

MINERAL AGGREGATE CONSERVATION **REUSE AND RECYCLING**

Prepared For
THE ONTARIO MINISTRY OF NATURAL RESOURCES
Aggregate and Petroleum Resources Section

By
JOHN EMERY GEOTECHNICAL ENGINEERING LIMITED
(JEGEL)



FEBRUARY 1992



Ministry of
Natural
Resources

Ontario

© 1992, Queen's Printer for Ontario
Printed in Ontario, Canada

Single copies of this publication may be purchased at the address noted below.

Current publications of the Ontario Ministry of Natural Resources, and price lists, are obtainable through the Natural Resources Information Centre, M1-73, Macdonald Block, 900 Bay Street, Toronto, Ontario M7A 2C1 (personal shopping and mail orders).

Telephone inquiries about ministry programs and services should be directed to the Natural Resources Information Centre:

General Inquiry	(416) 314-2000
Renseignements en français	314-1665
FAX	314-1593
Fisheries/Fishing Licence Sales	314-1177
Wildlife/Hunting Licence Sales	314-2225
Provincial Parks	314-1717
Forestry/Lands	314-1553
Aerial Photographs	314-2001
Maps	314-1666

Other government publications are available from Publications Ontario, Main Floor, 880 Bay St., Toronto. For mail orders write MGS Publications Services Section, 5th Floor, 880 Bay St., Toronto, Ontario M7A 1N8.

Cheques or money orders should be made payable to the Treasurer of Ontario, and payment must accompany order.

Cover Photograph—Recycling of Old Asphalt Pavement - Pile of Reclaimed Old Asphalt Pavement (RAP), Processing RAP, Stockpile of Processed RAP and Highway Asphalt Pavement With Recycled Hot-Mix Asphalt Concrete (RHM) Incorporating RAP.

Above Photograph—Waste to Resource - Pile of Reclaimed Old Concrete (RCM) and RAP, and Stockpile of Processed RAP for Use in RHM.

All Study Photographs by JEGEL.

INDEX

PAGE NO.

ACKNOWLEDGEMENTS	i
EXECUTIVE SUMMARY	ii
SOMMAIRE EXÉCUTIF	iii
1. INTRODUCTION	1
1.1 SCOPE AND METHODOLOGY	2
1.2 USE OF AGGREGATES IN ONTARIO	3
2. AVAILABILITY OF SUITABLE WASTES AND BYPRODUCTS	6
2.1 GENERAL CRITERIA FOR REUSE AND RECYCLING	6
2.2 WASTES AND BYPRODUCTS CONSIDERED	7
2.3 INVENTORY OF ONTARIO WASTES AND BYPRODUCTS	7
3. WASTES AND BYPRODUCTS	9
3.1 OLD ASPHALT	9
3.1.1 Major Sources, Availability and Uses	14
3.1.2 Storage and Processing	17
3.1.3 Technical, Environmental and Economic Factors	17
3.1.4 Research and Development	19
3.1.5 Impediments to Increased Use	19
3.1.6 Comment	20
3.2 OLD CONCRETE	22
3.3 BLAST FURNACE SLAG	23
3.4 STEEL SLAG	25
3.5 NICKEL AND COPPER SLAGS	28
3.6 FLY ASH AND BOTTOM ASH	29
3.7 CEMENT AND LIME KILN DUSTS	30
3.8 WASTE FOUNDRY SAND	32
3.9 MINE WASTES	33
3.10 MISCELLANEOUS WASTE	33
3.10.1 Demolition Wastes	33
3.10.2 Waste Shingles	34
3.10.3 Waste Tires	34
3.10.4 Waste Glass	35
3.10.5 General	35
4. FACTORS INHIBITING AND SUPPORTING REUSE AND RECYCLING	35
4.1 INHIBITING FACTORS	35
4.2 SUPPORTING FACTORS	36
5. CONCLUSIONS	37
6. RECOMMENDATIONS	38
REFERENCES	39
APPENDICES	43

TABLES

TABLE 1	ONTARIO AGGREGATES PRODUCTION	3
TABLE 2	ONTARIO USE OF AGGREGATES	4
2A	ONTARIO USE OF SAND AND GRAVEL IN 1987	
2B	ONTARIO USE OF STONE IN 1987	
TABLE 3	ONTARIO 1988 STRUCTURAL MATERIALS PRODUCTION	4
TABLE 4	OVERALL EVALUATION OF WASTES AND BYPRODUCTS FOR USE IN ROAD CONSTRUCTION, OECD, 1977	7
TABLE 5	WASTE AND BYPRODUCTS USED IN PROVINCES (P) AND STATES (S) SUMMARY OF SURVEY 1990 INFORMATION FROM TRANSPORTATION DEPARTMENTS	8
TABLE 6	MINISTRY OF TRANSPORTATION REGIONS, DISTRICTS AND JURISDICTIONS OF MUNICIPAL ENGINEERS	11
TABLE 7	ONTARIO WASTES AND BYPRODUCTS USE RANKING, 1990 USE, AND AVAILABILITY	13
TABLE 8	MAJOR ONTARIO WASTES AND BYPRODUCTS 1990 USE AND AVAILABILITY BY MNR REGIONS AND GTA	14
TABLE 9	ONTARIO USE OF OLD ASPHALT	16
9A	ONTARIO USE OF OLD ASPHALT (RAP) IN 1990 BY MNR REGIONS/DISTRICTS	16
9B	ONTARIO USE OF OLD ASPHALT (RAP) IN 1990 BY MTO REGIONS/DISTRICTS	16
TABLE 10	ONTARIO USE OF OLD CONCRETE	20
10A	ONTARIO USE OF OLD CONCRETE (RCM) IN 1990 BY MNR REGIONS/DISTRICTS	20
10B	ONTARIO USE OF OLD CONCRETE (RCM) IN 1990 BY MTO REGIONS/DISTRICTS	21
TABLE 11	TYPICAL COMPOSITIONS OF FERROUS AND NONFERROUS SLAGS	24
TABLE 12	BLAST FURNACE SLAG USED (PRODUCED) IN 1990 AND STOCKPILED	24
TABLE 13	ONTARIO GROUND PELLETIZED AND GRANULATED SLAG (SLAG CEMENT, GGBFS) PRODUCTION IN 1990 AND INVENTORY	25
TABLE 14	STEEL SLAG USED (PRODUCED) IN 1990 AND STOCKPILED	26
TABLE 15	ONTARIO NICKEL AND COPPER SLAGS USED (PRODUCED) IN 1990 AND STOCKPILED	27
TABLE 16	ONTARIO FLY ASH AND BOTTOM ASH PRODUCTION AND USE IN 1990 AND STOCKPILED	27

TABLE 17	ONTARIO CEMENT KILN DUST PRODUCTION IN 1990 AND STOCKPILED	28
TABLE 18	ONTARIO LIME KILN DUST PRODUCTION IN 1990 AND STOCKPILED	29
TABLE 19	ONTARIO WASTE FOUNDRY SAND 1989 PRODUCTION AND USE/DISPOSAL SITE	29
TABLE 20	ONTARIO PRODUCTION OF MINE WASTES - WASTE ROCK AND TAILINGS	31
20A	ONTARIO MINE WASTES 1990 PRODUCTION AND STOCKPILED BY MNR REGION	31
20B	ONTARIO MINE WASTES 1990 PRODUCTION AND STOCKPILED BY MTO REGION	32
TABLE 21	STATE LEGISLATION (1990) WASTE AND BYPRODUCTS USE IN CONSTRUCTION APPLICATIONS	35

FIGURES

FIGURE 1	SURVEY FORM ON WASTES AND BYPRODUCTS REUSE AND RECYCLING SENT TO PROVINCIAL AND STATE TRANSPORTATION DEPARTMENTS	5
FIGURE 2	REORGANIZED MINISTRY OF NATURAL RESOURCES (MNR) REGIONS AND DISTRICTS AND USE OF WASTES AND BYPRODUCTS IN 1990 BY MNR REGIONS	10
FIGURE 3	GREATER TORONTO AREA (GTA)	12
FIGURE 4	FLOW DIAGRAM OF IRON AND STEEL PRODUCTION SHOWING BYPRODUCT BLAST FURNACE AND STEEL SLAGS	21
FIGURE 5	FLOW DIAGRAM OF COAL FUEL POWER PLANT SHOWING WASTE FLY ASH AND BOTTOM ASH	29

PHOTOGRAPHS

PHOTOGRAPH 1	LARGE PILE OF OLD ASPHALT PAVEMENT (RAP) WITH SMALL PILE OF OLD CONCRETE (RCM) TO LEFT, DOWNSVIEW	17
PHOTOGRAPH 2	OLD ASPHALT PAVEMENT (RAP) PROCESSING PLANT (CRUSHING, SCREENING AND STOCKPIILING) FOR RAP USE IN RECYCLED HOT MIX (RHM), DOWNSVIEW	17
PHOTOGRAPH 3	STOCKPILE OF PROCESSED RAP FOR USE IN RHM, DOWNSVIEW. PROCESSED RAP CONTAINS BOTH AGGREGATE AND AGED ASPHALT CEMENT	18

PHOTOGRAPH 4	STOCKPILE OF CONVENTIONAL AGGREGATE FOR USE IN HOT MIX, MILTON. RAP USE IN RHM REPLACES BOTH AGGREGATE AND ASPHALT CEMENT	18
PHOTOGRAPH 5	ASPHALT BATCH PLANT EQUIPPED TO USE RAP (ABOUT 25 PERCENT) IN RHM WITH RAP FEED BIN TO RIGHT AND CONVEYOR TO PLANT MIXER, DOWNSVIEW	18
PHOTOGRAPH 6	OLD CONCRETE (RCM) PROCESSING PLANT (CRUSHING AND SCREENING) TO PRODUCE GRANULAR BASE (NOTE REMOVED REINFORCING STEEL), DOWNSVIEW	19
PHOTOGRAPH 7	HOT, IN-PLACE RECYCLING OF ASPHALT PAVEMENT USING TWO PREHEATERS AND A REFORMING MACHINE, MISSISSAUGA	19
PHOTOGRAPH 8	FULL DEPTH COLD RECYCLING OF ASPHALT PAVEMENT WITH GRANULAR BASE (NO EMULSIFIED ASPHALT ADDITION), OAKVILLE	19
PHOTOGRAPH 9	COLD, IN-PLACE RECYCLING OF ASPHALT PAVEMENT USING A MILLING MACHINE, CRUSHER, MIXER (EMULSIFIED ASPHALT ADDITION) AND PAVER TRAIN, MARKHAM	20

APPENDICES

APPENDIX A	DEFINITIONS	43
APPENDIX B	SPECIFICATIONS	49
	B 1 GENERAL	49
	B 2 USE OF AGGREGATES IN PAVEMENTS	49
	B 2.1 General	49
	B 2.2 Pavement Structures	49
	B 2.2.1 Functions and Characteristics of Flexible Pavement Structure Layers	50
	B 2.3 General Requirements for Aggregates in Pavements	51
	B 2.4 Granular Materials	51
	B 2.4.1 Granular Base	51
	B 2.4.2 Treated Granular Bases	53
	B 2.4.3 Unshrinkable Fill	53
	B 2.4.4 Cementitious Fly Ash Grout	53
	B 2.4.5 Lightweight Fill	53
	B 2.5 Asphalt Materials	54
	B 2.5.1 Hot-Mix Asphalt Concrete	54
	B 2.5.2 Cold-Mix Asphalt Concrete	55
	B 2.5.3 Surface Treatments	55
	B 2.5.4 Other Asphalt Surface Treatments	56
	B 2.6 Portland Cement Concrete	56
	B 2.7 Pavement Rehabilitation	56
	B 2.7.1 Hot-Mix Resurfacing	56
	B 2.7.2 Partial-Depth Removal and Hot-Mix Resurfacing	57
	B 2.7.3 In-Place Recycling	57
	B 2.7.4 Full-Depth Removal and Replacement with Recycled Hot Mix (RHM)	57

	B 2.7.5	Cold Mix with Sealed Surface Course (Midland Mix Paver)	57
	B 2.7.6	Surface Treatments	58
	B 2.7.7	Pulverization and Remixing Prior to Resurfacing	58
	B 3	TYPICAL SPECIFICATION PROVISIONS FOR WASTES AND BYPRODUCTS USE	58
	B 3.1	Aggregate Uses	58
	B 3.2	Cementitious Uses	60
	B 4	REFERENCES	61
	B 4.1	Specifications and Uses	61
	B 4.2	General Design Manuals and Handbooks	62
	B 4.3	Obtaining Specifications, Design Manuals and Handbooks	63
TABLES			
B1		ONTARIO PROVINCIAL STANDARD SPECIFICATION (OPSS 1010) REQUIREMENTS FOR GRANULAR MATERIALS	52
B2		COARSE AND FINE AGGREGATE SOURCES FOR SURFACE COURSE HMA	55
FIGURE			
B1		FLEXIBLE AND RIGID PAVEMENT STRUCTURES	50
APPENDIX C			
C 1		KEY CONTACTS FOR ASSISTANCE SIGNIFICANT INTEREST IN WASTES AND BYPRODUCTS USE AS AGGREGATES	64 65
C 2		GENERAL INTEREST IN WASTES AND BYPRODUCTS AS AGGREGATES	65
C 3		GENERAL INTEREST IN WASTE MANAGEMENT (REDUCTION, REUSE AND RECYCLING)	66
C 4		GENERAL REFERENCES ON WASTE MANAGEMENT (REDUCTION, REUSE AND RECYCLING)	66
APPENDIX D			
D 1		METRIC CONVERSIONS AND ABBREVIATIONS METRIC CONVERSIONS	68 68
D 2		ABBREVIATIONS	68

ACKNOWLEDGEMENTS

The valuable contribution of information, data, technical references and advice to the study by many organizations and individuals is gratefully acknowledged. The guidance of the Ministry of Natural Resources Study Manager (Dr. Pervez Umar) and advisors (Ray Pichette and Doug Vanderveer) was particularly helpful at all stages of the study. The John Emery Geotechnical Engineering Limited (JEGEL) study staff would particularly like to thank the following organizations for the considerable time spent on technical and inventory discussions:

Ontario Ministry of Natural Resources
Aggregate and Petroleum Resources Section
Pervez Umar, Ray Pichette and Doug Vanderveer

Ontario Ministry of Transportation
Engineering Materials Office
Zoltan Katona, Dan Lynch and Chris Rogers

Ontario Hot Mix Producers Association Members
and
Ontario Road Builders Association Members.

MINERAL AGGREGATE CONSERVATION REUSE AND RECYCLING EXECUTIVE SUMMARY

The role of wastes and byproducts reuse and recycling in Ontario aggregates conservation has been considered through the following interacting elements:

1. technology for wastes and byproducts reuse and recycling as aggregates in bulk and cementitious applications;
2. current and potential sources, quantities and use of suitable wastes and byproducts;
3. factors encouraging reuse and recycling, and their enhancement, including relevant legislation;
4. factors discouraging reuse and recycling, and their mitigation;
5. current and potential contribution of reuse and recycling to Ontario aggregates conservation, and particularly the impact on the Greater Toronto Area;
6. economics of wastes and byproducts reuse and recycling as aggregates for bulk and cementitious applications; and
7. actions such as policy changes, incentives and specification modifications to foster and extend such reuse and recycling.

There are seven wastes and byproducts commonly used in construction as aggregates in bulk and cementitious applications. These include old asphalt, old concrete, blast furnace slags, steel slag, nickel and copper slags, fly ash and bottom ash which currently make a significant contribution to materials and landfill space conservation in Ontario. Other wastes of potential interest include kiln dusts, foundry sand, demolition wastes and mine waste rock, particularly mine waste rock if favourable transportation costs develop allowing use in Southern Ontario. The current (1990) use of wastes and byproducts in construction for bulk and cementitious applications is about 6 million tonnes out

of some 11 million tonnes annual production of potentially suitable wastes and byproducts. This equates to about 3 percent of Ontario's total aggregate production. Some 3 million tonnes of this 11 million tonnes of wastes and byproducts of potential interest, such as mine waste rock, is either not within economic transportation distance to markets or is of marginal technical quality. Based on current trends and optimistic use projections, the 1995 estimated use of wastes and byproducts in construction ranges between 6 to 9 million tonnes, or 3 to 5 percent of Ontario's total production of aggregates. The proportional impact of such aggregates conservation in the Greater Toronto Area is similar.

It is recommended that standard specifications (Ontario Provincial Standard Specifications action), environmental guidance (Ministry of the Environment/Ministry of Transportation action) and wider range of uses for wastes such as old asphalt and old concrete (Ministry of Transportation action), be developed to foster the use of wastes and byproducts in construction. The resolution of the pavement map cracking problem associated with steel slag use in hot-mix asphalt, by joint Ministry of Transportation and paving industry action, is critical to preserving this important aggregate source.

The prime factors providing favourable economics for the use of wastes and byproducts in construction include the government policies of sustainable development and landfill restrictions such as the banning of recyclable materials from landfills in Metro Toronto.

The contribution of wastes and byproducts use and recycling as aggregates is significant to resource and landfill conservation. However, it will continue to have only a small (3 to 5 percent) overall impact on Ontario aggregates requirements given the already high usage (66 percent) of the available wastes and byproducts of suitable technical quality within economic transportation distance.

CONSERVATION, RÉCUPÉRATION ET RECYCLAGE DES GRANULATS MINÉRAUX

SOMMAIRE EXÉCUTIF

Le rôle de la récupération et du recyclage des déchets et des sous-produits dans la conservation des ressources en granulats de l'Ontario a été étudié en fonction des éléments interreliés suivants:

1. la technologie de récupération et de recyclage des déchets et des sous-produits pour leur utilisation comme granulats en vrac et en amalgame;
2. les sources actuelles et potentielles de déchets et de sous-produits appropriés, ainsi que leur quantité et leur utilisation;
3. les facteurs favorisant la récupération et le recyclage ainsi que la promotion de ces activités, y compris par l'adoption de mesures législatives pertinentes;
4. les facteurs décourageant la récupération et le recyclage, ainsi que leur atténuation;
5. la contribution actuelle et potentielle de la récupération et du recyclage à la conservation des granulats en Ontario, et en particulier l'incidence de ces activités dans la région du Toronto métropolitain;
6. les aspects économiques de la récupération et du recyclage des déchets et des sous-produits pour leur utilisation comme granulats en vrac ou en amalgame;
7. les mesures telles que les changements d'orientation et les modifications à apporter aux mesures d'encouragement et aux normes en vue de promouvoir et d'étendre les activités de récupération et de recyclage.

Il y a sept types de déchets et de sous-produits couramment utilisés comme granulats en vrac ou en amalgame dans la construction des chaussées et qui contribuent de façon importante à la conservation des matériaux et des décharges en Ontario. Ce sont le bitume récupérable, le béton récupérable, les scories des hauts fourneaux, les scories d'acier, les scories de nickel et de cuivre, les cendres volantes et les cendres lourdes. D'autres déchets présentent également un intérêt potentiel, soit les poussières des fours, le sable de fonderie, les déchets de démolition et les déchets miniers rocheux. Ces derniers offrent un intérêt particulier si des frais de transport abordables permettent leur utilisation dans le sud de l'Ontario. En 1990, on utilisait près de 6 millions de tonnes de déchets et de sous-produits en vrac ou en amalgame dans la construction des chaussées,

soit l'équivalent d'environ 3 p. 100 de la production ontarienne de granulats. La même année, le total des déchets et des sous-produits potentiellement appropriés s'élevait à environ 11 millions de tonnes. De ce total, près de 3 millions de tonnes de déchets et de sous-produits présentant un certain intérêt, en particulier les déchets miniers rocheux, ne sont pas économiquement rentables en raison des distances de transport ou ne possèdent qu'une qualité technique marginale. On évalue qu'en 1995 on utilisera entre 6 et 9 millions de tonnes de déchets et de sous-produits dans la construction des chaussées, soit entre 3 et 5 p. 100 de la production ontarienne de granulats, si l'on se fie, respectivement, aux tendances actuelles et aux prévisions d'utilisation les plus optimistes. L'incidence d'une telle conservation des granulats sur le territoire du Toronto métropolitain a proportionnellement la même importance.

Le rapport recommande l'élaboration de normes (responsabilité du Bureau des normes provinciales de l'Ontario [Ontario Provincial Standard Specifications]), de lignes directrices en matière d'environnement (responsabilité du ministère de l'Environnement et du ministère des Transports), et d'une gamme plus étendue d'emplois de déchets tels que le bitume et le béton récupérables (responsabilité du ministère des Transports) en vue de promouvoir l'utilisation des déchets et des sous-produits dans la construction des chaussées. La résolution des problèmes de fissuration des chaussées liés à la présence de scories d'acier dans les mélanges de bitume préparés à chaud, grâce à une action conjointe du ministère des Transports et de l'industrie du pavage, est essentielle pour la conservation de cette importante source de granulats.

Les principaux facteurs qui favorisent la rentabilité économique de l'utilisation des déchets et des sous-produits dans la construction des chaussées sont les politiques gouvernementales en matière de développement durable et les restrictions imposées aux décharges, notamment l'interdiction de la mise en décharge des matières recyclables sur le territoire du Toronto métropolitain. L'utilisation et le recyclage des déchets et des sous-produits comme granulats constituent un apport important à la conservation des ressources et des décharges. Par ailleurs, étant donné l'utilisation déjà élevée des déchets et des sous-produits disponibles, possédant une qualité technique adéquate et situés à des distances de transport économiquement rentables, ces activités continueront de n'avoir qu'une faible incidence sur l'ensemble des besoins de l'Ontario en matière de granulats (entre 3 et 5 p. 100 des besoins).



1. INTRODUCTION

Users of the transportation and building infrastructure of Ontario may have observed large piles of apparently discarded materials such as old asphalt pavement*, old concrete and slags. Actually, the reuse and recycling of such wastes and byproducts as construction materials is making a modest, but significant, contribution to aggregates conservation and particularly reduced landfill requirements. There may also be energy and/or cementitious materials conservation involved with old pavement asphalt cement content reuse and blended cements. This Ministry of Natural Resources (MNR) study on mineral aggregates conservation through reuse and recycling is particularly timely. The nurturing and expansion of reuse and recycling of wastes and byproducts requires: cost-effective, environmentally sound and state-of-the-art collection, storage and processing; and incorporation and distribution technologies meeting reasonable recycled aggregates specifications (Miller and Collins, 1976; Clifton, Brown and Frohnsdorff, 1977; OECD, 1977; Gutt and Nixon, 1978; Emery, 1984)**. The current Ontario focus on resource conservation (MOE, 1990) to reduce landfill requirements, including the 3Rs of reduction, reuse and recycling, and sustainable development, is addressed proactively by this study.

There is increasing waste management environmental pressure to keep all potentially reusable and recyclable materials from ever-scarce landfills. This is particularly acute in the Greater Toronto Area (GTA) (Ferguson, 1989). There is also pressure to conserve aggregate resources, such as concern for sensitive areas like the Niagara Escarpment (NEC, 1991). These pressures, coupled with a growing demand for aggregates of some 20 tonnes annually per capita for Ontario (MNR, 1990), would seem to provide the ideal climate for reuse and recycling. However, there are significant limiting factors to be faced and surmounted such as: agency conservatism; obsolete specifications; inadequate research and development budgets; liability concerns for innovative technologies; environmental constraints on recyclable wastes that are not applied to conventional materials; industry processing and pricing based on new materials; wide distribution of wastes; collection, storage and processing costs; lack of technical guidance; and the inherent variability of many wastes and byproducts (Emery, 1978; MNDM, 1990;

ENDS, 1991). For example, the Ministry of Transportation (MTO) has developed a number of Special Provisions 'encouraging' the use of suitably processed old asphalt and old concrete*. Unfortunately, many municipalities are either not aware of these uses with appropriate specifications, or may still require all new aggregates in their pavements. For these municipalities, the piles of old asphalt pavement and old concrete can only grow, and the landfills unfortunately fill with potential aggregate resources.

Rather than being too pessimistic with all these limitations at this introductory point, it should be noted at the outset that Ontario, particularly the road construction industry, is making surprisingly good use of economically available, technically suitable wastes and byproducts as aggregates. It will be shown that about seventy percent of the annually available wastes and byproducts of interest in Ontario are being used in bulk and cementitious applications. This amounts to about six million tonnes of wastes and byproducts annually, or three percent of Ontario's annual aggregates consumption. Mining wastes have generally been excluded from consideration due to factors such as inherent variability, acid leachability and transportation costs. Based on surveys for the study, Ontario's involvement with wastes and by products reuse and recycling as aggregates appears to be in advance of other provinces and most U.S. states. This should grow as more wastes are banned from landfills (MOE, 1990; Ferguson, 1989). For example, the key themes of the Ontario Hot Mix Producers Association (OHMPA) 1990 fall asphalt seminar "Paving the Way" were: the role of aggregates in premium hot mix performance; future supply and quality of hot-mix aggregates; hot mix and the environment; and recycling old asphalt (OHMPA, 1990). Clearly, this study is concerned with the evolution and encouragement of wastes and byproducts reuse and recycling as aggregates, rather than a 1990s revolution to get reuse and recycling started.

The study deals with specific wastes and byproducts of greatest technical and volume potential as both bulk and cementitious materials for mineral aggregates conservation. Determining the wastes and byproducts of greatest interest required an extensive inventory of Ontario wastes and byproducts activity, and a survey of Canadian, American and International reuse and recycling. The necessary reuse and recycling technical

*See Appendix A for a list of definitions.

**See list of References at the end.

*See Appendix B for a list of applicable specifications.

guidance is documented, mainly in the form of available references, specifications and design manuals, such as in Appendix B. Particular attention is given to agency and industry factors identified that should be addressed through policy changes, incentives and/or specification modifications to foster aggregate conservation. For example, the use of processed, washed steel slag as aggregate in hot-mix asphalt has been developed to take advantage of its good frictional and stability properties. However, deleterious components are now causing severe usage constraints (Metro, 1991b). Obviously, this must be technically resolved to preserve this important steel slag use of some 400,000 tonnes per annum in Southern Ontario.

The most important wastes and byproducts reused and recycled as construction materials are old asphalt, old concrete, blast furnace slag, steel slag, nickel and copper slags, fly ash and bottom ash. Other wastes and byproducts of interest include lime and cement kiln dusts, waste foundry sand, mine wastes, demolition wastes, waste shingles, waste tires and waste glass. The wastes and byproducts have a range of construction uses in both bulk materials applications such as aggregates, engineered fill, shore protection and fillers, and cementitious materials applications such as cement kiln feed, stabilization and blended cements.

1.1 SCOPE AND METHODOLOGY

The reuse and recycling study scope consists of seven interacting elements to meet the Ministry of Natural Resources' (MNR) objectives:

1. state-of-the-art technology for wastes and byproducts reuse and recycling as aggregates (bulk and cementitious applications) in Ontario, including research and development, based on world-wide experience;
2. current and potential sources and quantities (rate of production and/or stockpiled) of suitable wastes and byproducts in Ontario that are being reused or recycled as aggregates, or have the potential for such reuse or recycling;
3. factors encouraging wastes and byproducts reuse and recycling as aggregates in Ontario, and their enhancement, including comparative summary of relevant North American legislation;
4. factors discouraging wastes and byproducts reuse and recycling as aggregates in Ontario, and their mitigation, including a summary of typical actions by North American agencies in terms of policy, incentives and/or specification modifications;
5. current and potential contribution of wastes and byproducts reuse and recycling as aggregates to extending Ontario's overall aggregate reserves, and specifically, the impact for the Greater Toronto Area (GTA);
6. economics of wastes and byproducts reuse and recycling as aggregates in Ontario in terms of factors such as plant requirements, plant locations, transportation, storage, processing and distribution costs, cost recovery through dumping charges, competitive pricing with conventional aggregates and profit margins; and
7. recommendations on any Ontario provincial or agency actions, such as policy incentives and/or specification modifications, identified to foster the reuse and recycling of wastes and byproducts as aggregates.

The state-of-the-art technology for wastes and byproducts reuse and recycling as aggregates (bulk and cementitious application), and associated information such as encouraging and discouraging factors, policy and incentives, was developed from:

1. review of extensive internal, JEGEL technical files on wastes and byproducts utilization developed over the past fifteen years, starting with OECD and RILEM studies (OECD, 1977; Gutt and Nixon, 1978; Emery, 1978);
2. abstract searches for asphalt recycling, concrete recycling, demolition waste, mining waste, copper slag, lead slag, nickel slag, foundry sand, phosphogypsum and tire recycling using the DIALOG[®] TRIS (Transportation Research Information Service) Database (Dialog, 1991);
3. survey of wastes (residuals) and byproducts reuse and recycling, specifications and legislation, by Canadian provinces and territories and American states and District of Columbia transportation departments, using the form in Figure 1 (100 percent response achieved by telephone follow-ups);

4. interviews and discussions with staff involved with waste and byproduct utilization in government agencies (MTO), contractors and industry (OHMPA members for instance), owners (Daniels Group for instance) and consultants (Manufacturing Research Corporation of Ontario (MRCO)), including contacts in Britain, Denmark, Finland, France, Germany, Norway and Sweden;
5. detailed wastes and byproducts availability and utilization inventory development (old asphalt, old concrete, blast furnace slag, steel slag, nickel and copper slags, fly ash, kiln dusts, bottom ash, foundry sand and mine wastes) by MNR and MTO regions/ districts, and GTA, through mainly telephone contacts with contractor and industry staff; and
6. follow-ups, and integration of information and data, on wastes and byproducts reuse and recycling as aggregates (bulk and cementitious applications) of particular interest.

The wastes and byproducts inventory activity was particularly important as a database for the study, but time consuming as little industry sector data was available with the exceptions of fly ash, bottom ash and foundry sand. In key areas such as old asphalt and old concrete recycling, there were not even lists of plant locations available. It was found that the JEGEL technical files on wastes and byproducts utilization for

each material are generally more comprehensive than the TRIS database of references and information from the survey, interview, discussion, inventory and follow-up activities. Given the large amount of data and information generated, extensive use of tables has been adopted throughout this report.

1.2 USE OF AGGREGATES IN ONTARIO

Before turning to the use of wastes and byproducts as aggregates in Ontario, it is important to recognize the overall role that conventional aggregates play in the Ontario economy and infrastructure. As shown in Table 1 for 1985 to 1989, the annual use of conventional aggregates (sand, gravel and stone used for construction or industrial processes) approached 200 million tonnes. This was probably down to about 180 million tonnes for 1990 due to a slower economy. About 25 percent of Provincial aggregate production is in the GTA (Metro Toronto, Halton, Peel, York and Durham Regions), while consumption is to the tune of 40 percent of Ontario's production (MNDRM, 1990; EMR, 1990; APAO, 1988). As set out in Table 2, the major uses of sand, gravel and crushed stone are in roads, concrete aggregates and asphalt aggregates; approximately 73 percent of Ontario use of aggregates is for these three applications. Ontario is the leading province in both quantity and value of structural materials production (building materials, lime, stone, sand and gravel), as summarized in Table 3 for 1988.

TABLE 1 ONTARIO AGGREGATES PRODUCTION*

CATEGORY/YEAR	1985	1986	1987	1988	1989	5 YEAR AVERAGE
MILLION TONNES						
Pits and Quarries Control Act Licences**	106	128	149	154	154	138
Pits and Quarries Control Act Wayside Permits	5	6	5	5	4	5
MTO Crown Land/Private Non-designated	8	7	7	8	8	8
Crown Land	13	12	11	16	16	14
Private Land Non-designated	13	12	13	14	15	13
TOTAL	145	165	185	197	197	178

*1989 Ministry of Natural Resources Aggregate Resources Program Statistical Update.

**Pits and Quarries Control Act replaced by the Ontario Aggregate Resources Act in January 1990.

TABLE 2 ONTARIO USE OF AGGREGATES*
TABLE 2A ONTARIO USE OF SAND AND GRAVEL IN 1987**

USE/QUANTITY	1000 TONNES	PERCENT
Roads	50,819	52.8
Concrete Aggregate	19,231	20.0
Asphalt Aggregate	6,193	6.4
Fill	15,085	15.7
Mortar Sand	2,235	2.3
Mine Backfill	698	0.7
Railroad Ballast	284	0.3
Other Uses	1,706	1.8
TOTAL	96,251	100.0

*Less than Table 1 total as mainly Pits and Quarries Control Act sources.

**1989 Canadian Minerals Yearbook, Energy, Mines and Resources Canada (EMR, 1990).

TABLE 2B ONTARIO USE OF STONE IN 1987*

USE/QUANTITY**	1000 TONNES	PERCENT
Crushed Stone		
Roads	31,163	50.5
Concrete Aggregate	4,581	7.4
Asphalt Aggregate	4,432	7.2
Fill	5,401	8.8
Other Uses	1,701	2.8
Total Crushed Stone	47,278	76.7
Chemical Process Stone	11,452	18.6
Pulverized Stone	712	1.2
Dimensional Stone	79	0.1
Miscellaneous Stone	2,183	3.4
TOTAL	61,704	100.00

*Ministry of Northern Development and Mines (MNDM, 1990).

**Stone sold and consumed by stone producers.

TABLE 3 ONTARIO 1988 STRUCTURAL MATERIALS PRODUCTION*

USE/PRODUCTION	OPERATIONS	QUANTITY 1000 TONNES	PERCENT OF CANADIAN TOTAL	VALUE \$1000	PERCENT OF CANADIAN TOTAL
Building Materials					
Gypsum	3	1,459		19,712	
Cement	5 plants, 16 kilns	5,533 ***	44.8	436,269	44.9
Clay Products	17	—		122,203	
Lime	8	1,666		114,374	
Stone**	—	58,460	47.9	313,141	48.8
Sand and Gravel**	—	104,838	36.2	336,156	39.0

*1989 Canadian Minerals Yearbook, Energy, Mines and Resources Canada (EMR, 1990).

**Less than Table 1 total as mainly Pits and Quarries Control Act sources.

***Clinker and grinding capacity about 6 million tonnes per year.

**SURVEY
MINERAL AGGREGATE CONSERVATION
REUSE AND RECYCLING**

Name: _____ Agency: _____

1. Does your agency use any of the following residuals or byproducts as substitutes for current natural aggregate and aggregate-related uses? Please circle if used; underline if other agencies in your jurisdiction use any of these and indicate the agency below.

- a. Blast Furnace Slag: Air Cooled/Pelletized/Granulated;
b. Nickel Slag: Air-Cooled/Granulated;
c. Copper Slag: Air-Cooled/Granulated;
d. Old Asphalt; e. Old Concrete; f. Steel Slag;
g. Ferro Alloy Slags; h. Foundry Sand; i. Bottom Ash;
j. Mine Waste Rock; k. Mine Tailings; l. Waste Wood;
m. Other: Refractory Waste, Demolition Waste, Waste Gypsum, Boiler Slag, Dredge Spoil, Marginal Aggregates, Other _____

Other Agencies: _____

2. Does your agency use any of the following residuals or byproducts as replacements in manufacturing processes or substitutes for materials in cementitious applications? Please circle if used; underline if other agencies in your jurisdiction use any of these and indicate agency below.

- a. Blast Furnace Slag: Pelletized/Granulated; b. Granulated Copper Slag;
c. Granulated Nickel Slag; d. Fly Ash; e. Sulphate Wastes;
f. Cement Kiln Dust; g. Lime Kiln Dust; h. Waste Tires and Rubber;
i. Other: Silica Fume, Resins/Lignins, Waste Shingles, Waste Plastic, Cellulosic Waste, Surplus Sulphur.

Other Agencies: _____

3. Do you have any legislation currently in place or proposed that promotes or requires the reuse of any specific residuals or byproducts? If yes, please send a copy.
4. Do you have any specific specifications that cover the reuse of residuals or byproducts for aggregate or aggregate-related uses? If yes, please send copies.
5. What factors encourage the recycling and reuse of residuals and byproducts in your jurisdiction? Please circle.
- a. lower cost; b. superior performance; c. lack of suitable aggregates;
d. waste reduction; e. other _____
6. Are there any specific items that discourage you from substituting residuals or byproducts for aggregate or aggregate-related uses? Please circle.
- a. higher cost; b. poor performance; c. supply problems;
d. lack of technical literature or performance data; e. other _____

PLEASE FEEL FREE TO ATTACH ADDITIONAL COMMENTS

PLEASE RETURN BY FAX TO 416-630-7045

FIGURE 1 SURVEY FORM ON WASTES AND BYPRODUCTS REUSE AND RECYCLING SENT TO PROVINCIAL AND STATE TRANSPORTATION DEPARTMENTS

It is clear from the Ontario conventional aggregates production and use data, that there is wide scope for wastes and byproducts reuse and recycling in overall aggregates conservation. This is particularly the case in the transportation infrastructure construction and maintenance sector. Use of wastes and byproducts in road construction tended to be the focus of past utilization activities (OECD, 1977; Gutt and Nixon, 1978), and continues to be the most promising for Ontario as demonstrated in the following sections. This is most apparent for the GTA with its coupled high demand for aggregates and growing ban from landfills of recyclable material such as old asphalt and old concrete (Metro, 1991a).

2. AVAILABILITY OF SUITABLE WASTES AND BYPRODUCTS

2.1 GENERAL CRITERIA FOR REUSE AND RECYCLING

The initial screening criteria for the overall evaluation of wastes and byproducts for use in the construction industry, and subsequent steps in the technical and economic analyses of promising materials, have developed from the mid-70s Transportation Research Board (TRB), OECD and RILEM utilization studies (Miller and Collins, 1976; OECD, 1977; Gutt and Nixon, 1978) as follows:

1. quantity of material available at the location must be large enough to justify the development of handling, process, stockpiling and transportation systems:
 - i. for bulk applications (for example aggregates and engineered fill), about 45,000 tonnes per year or equivalent stockpile for several years; and
 - ii. for higher value added cementitious applications (blended cements and stabilization), smaller quantities are generally acceptable;
2. transportation distances involved must be reasonable in terms of competition with conventional aggregates (this precludes many northern Ontario sources of mine waste rock that are not near urban centres); and
3. processed material must not be potentially harmful either during use in construction or following incorporation into the structure (for

example, no leaching of toxic constituents, no soluble compounds, dusting controlled, etc.) (Emery, 1984).

Following the initial screening outlined above, the technical acceptability* of a promising waste or byproduct for various aggregate applications is considered in terms of the material's properties in relation to the requirements for the construction application contemplated (Emery, 1984). General and specific physical, mechanical and chemical properties of the material, or economically processed material, are compared with reasonable, applicable specifications. This will require recognition by the concerned agencies for the need for new construction materials and methods. Generally, wastes and byproducts with the highest potential for general aggregates use will have adequate soundness, hardness, gradation and particle shape, and resistance to chemical and physical deterioration, and require a minimum of processing such as crushing, blending and screening.

Finally, the overall economic/environmental feasibility for use of a technically acceptable waste or byproduct is evaluated in terms of: location, quantity and potential markets; technical requirements of applications; resource replacement value of bulk and/or cementitious applications; and ecological and social considerations such as resource conservation and sustainable development.

Based on the initial screening and technical economic/environmental evaluations, wastes and byproducts for bulk and cementitious use in construction can be grouped into one of four classes:

- | | |
|---------|---|
| Class 1 | wastes and byproducts of maximum potential that possess the best properties, either in their naturally occurring, processed or combined form, and/or have a record of satisfactory performance; |
| Class 2 | wastes and byproducts requiring more extensive processing and/or with properties not as adequate as Class 1; |
| Class 3 | wastes and byproducts having less promise than Classes 1 and 2 and recommended for use only in isolated situations; and |
| Class 4 | wastes and byproducts showing little promise as construction materials (generally not considered or listed). |

*For background on the use of aggregates in construction see Appendix B2. "Use of Aggregates in Pavements", with "Typical Specification Provisions for Wastes and Byproducts Use" given in Appendix B3.

From the 1977 OECD study (12 countries, including Canada), most wastes and byproducts of interest to Ontario industry are found in Class 1 of Table 4.

A more recent ranking of the 12 most important wastes and byproducts in the Canadian context is also shown in Table 4 (Emery, 1984). It should be noted that for the OECD 1977 study, old concrete and old asphalt were included as demolition wastes, but are now considered separately and are of greatest current importance to aggregates conservation in the GTA.

2.2 WASTES AND BYPRODUCTS CONSIDERED

The wastes and byproducts from Table 4 to be specifically considered in detail for Ontario were then subjectively selected on the basis of: JEGEL technical files (supplemented by DIALOG[®] abstracts); experience with the Ontario construction industry; discussions with agency, contractor/ owner, industry and consultant staff; and particularly the survey of

provincial and state transportation departments using the form in Figure 1. Scandinavian, British, French and German practices were generally found to be similar, or less advanced than current Ontario uses of wastes and byproducts in construction. A numerical summary of the provincial and state responses is given in Table 5. This includes agency specifications and regulations, with the wastes and byproducts listed in decreasing order of importance. The wastes and byproducts listed in Table 5, from old asphalt down to waste glass, are considered in some detail in the following sections.

2.3 INVENTORY OF ONTARIO WASTES AND BYPRODUCTS

With the focus wastes and byproducts established in Table 5, the time-consuming inventory of sources and quantities (use, production and stockpiled) was completed on the basis of MNR and MTO regions and districts, and GTA. MNR regions/districts prior to 1991 were used and the data subsequently converted to the

TABLE 4 OVERALL EVALUATION OF WASTES AND BYPRODUCTS FOR USE IN ROAD CONSTRUCTION, OECD, 1977*

CLASS 1	CLASS 2	CLASS 3
Blast Furnace Slags (1)**	Phosphate Slag	Gold Tailings
Fly Ash (2)	Copper Slag	Copper Tailings
Silica Fume (3)***	Quarry Waste	Lead-Zinc Tailings
Cement/Lime Kiln Dust (4)***	Mine Refuse	Coke breeze (6)
Sulphur (5)	Slate Waste	(Not Considered a Waste)
(Not Considered a Waste)	Bark and Sawdust (11)	Foundry Sand (12)
Steel Slag (7)	Fluorspar Tailings	Ceramic and Refractory
Boiler Slag (9)	Tires and Rubber (10)	Wastes
Bottom Ash (9)	Zinc Slag	Resins (11)
Nickel Slag (8)	Lead Slag	Lignins (11)
Demolition Wastes (6)	Mixed Ash	Potassium Salt
(Includes Old Concrete	Incinerator Residue	Mine Wastes
and Old Asphalt)		Pyrite Cinders
Colliery Spoil		Waste Glass and Cullet
Oil Shale Residue		Waste Plastics
Taconite Tailings		Cellulosic Wastes
China Clay Sand		
Iron Ore Tailing		
Pyrolysis Residue		

*Use of Waste Materials and Byproducts in Road Construction, OECD, 1977 (OECD, 1977).

**Number indicates overall evaluation of 12 most important wastes and byproducts in the Canadian context (Emery, 1984).

***Omitted from OECD overall evaluation.

**TABLE 5 WASTES AND BYPRODUCTS USED IN PROVINCES (P) AND STATES (S)
SUMMARY OF SURVEY 1990 INFORMATION FROM TRANSPORTATION DEPARTMENTS***

WASTES AND BYPRODUCT	BULK USES**		CEMENTITIOUS USES**		SPECIFICATIONS		REGULATIONS	
	P	S	P	S	P	S	P	S
Old Asphalt	10	42	(10)***	(42)	3	19		2
Old Concrete	4	29			1	8		2
Blast Furnace Slag								
Air-Cooled	2	18			1	12		
Pelletized	1		1	1	1			
Granulated	1	3	1	15	1	2		
Steel Slag	4	18			1	4		
Nickel and Copper Slags								
Air-Cooled	2	1			1	1		
Granulated		1						
Fly Ash	1	2	4	46	1	12		3
Kiln Dusts								
Cement				3				
Lime			1	6				
Bottom Ash	2	6				1		
Foundry Sand	1	2						1
Mine Waste Rock	4	10						
Waste Shingles		1		(1)				
Waste Tires	2	19	(2)	(19)		5		6
Waste Glass	1	2			1	2		3
Miscellaneous								
Boiler Slag		7				6		
Cellulosic Waste				1				1
Ceramic Waste		1				1		
Demolition Waste	1	2				1		
Dredge Spoil		2						
Foundry Slag						1		1
Marginal Aggregates	5	3						
Mine Tailings	3	8				1		
Phosphate Slag		1				1		
Refractory Waste		1						
Resins/Lignins			3	4		1		
Silica Fume			4	15	1	2		
Surplus Sulphur			2	1				
Tall Oil			2					
Used Oil						1		1
Waste Wood	2							
Waste Plastic				2				2
Waste Gypsum		2				2		

*10 Provinces plus Yukon and NWT (100 percent response) and 50 States plus District of Columbia (100 percent response) from the transportation departments.

**Also includes specific city, commercial and demonstration uses. The survey information has not been verified. See Figure 1 for the survey form used.

***Uses in brackets are bulk use with cementitious component

recently reorganized MNR regions/districts as shown on Figure 2. The MTO regions, districts and jurisdictions of municipal engineers are listed in Table 6, with the boundaries and municipal jurisdiction of the GTA given on Figure 3. Inventory information for Ontario wastes and byproducts reused and recycled as aggregates (bulk and cementitious applications) is summarized in Table 7 for the province and in Table 8 for MNR regions and the GTA. Additionally, the ranking of the wastes and byproducts of interest are given in Table 7. This provides the clearest picture of reuse and recycling in 1990, some 5.5 million tonnes (probably greater than 6 million tonnes if minor uses not quantified are included), or about three percent of Ontario's total aggregates production. Regional distribution, and proportion of wastes and byproducts use in Southern Ontario (about 65 percent of Ontario total), is shown clearly on Figure 2.

A detailed inventory information and use for each waste and byproduct by MNR and MTO regions/districts, and GTA, is given in following sections.

3. WASTES AND BYPRODUCTS

Each of the wastes and byproducts of interest listed in Tables 5 and 7 was considered in terms of: major sources, availability and uses; storage, processing and distribution; technical, environmental and economic factors; research and development; and impediments to increased use, if any. To illustrate the economic considerations involved, a cost analysis for old reclaimed asphalt pavement (RAP) use in recycled hot mix (RHM) in the GTA is given in detail. This can be used as a model to consider other wastes and byproducts for specific locations and uses. While general technical guidance is provided*, it is important that the actual suitability of a waste or byproduct be checked by testing the material for applicable specification compliance. This will also typically involve interaction with potential user agencies such as the MTO**, particularly if a record of satisfactory performance is not available for a new material and/or application. It is also important that specific contract requirements and current specifications be checked for each construction project.

3.1 OLD ASPHALT

There are large supplies of old asphalt pavement (RAP) available for reuse and recycling as a result of road and highway reconstruction and maintenance work across Ontario, as well as conservation of materials, energy and landfill space. This is particularly the case for the GTA. RAP use in recycled hot mix (RHM) is well developed in Ontario (see cover composite photograph), with MTO leadership and specifications (OPSS 1149*) and use by a growing number of other agencies (Metro Transportation MT 701*, 1991). RAP generally consists of coarse and fine aggregates (about 95 percent of total mix by mass) and aged asphalt cement binder (about 5 percent of total mix by mass).

The use of RAP in RHM recovers both the bulk component aggregate and the asphalt cement. By comparison, new aggregates and new asphalt cement would cost about \$11 per tonne and \$175 per tonne respectively at hot-mix plants in the GTA. Old asphalt pavement recycling can also be completed hot or cold in-place, with the use of both methods growing in use in Ontario (MTO Special Provision No. 310S08* for instance).

Of the range of cold and asphalt recycling methods available including blended granular material, full-depth cold processing, cold in-place train with emulsion, hot in-place and hot-mix plant. Hot-mix plant recycling of old asphalt is by far the most common method currently used in Ontario. Recycling of old asphalt to new asphalt mix requirements in Ontario by the hot-mix industry is an excellent example of favourable overall economics resulting in significant continuing conservation of aggregates, asphalt cement and landfill space, with attendant cost savings. These have been nurtured by agency leadership (MTO) and the development of reasonable specifications. However, the amount of RAP for recycling is increasing and there are still many agencies that do not accept RAP back into their asphalt mixes.

*See Appendix B for details on the use of aggregates in pavements, specific specification provisions for wastes and byproducts use and specification references.

**See Appendix C for a list of key contacts for assistance in the construction industry.

FIGURE 2
REORGANIZED MINISTRY OF NATURAL RESOURCES (MNR) REGIONS AND DISTRICTS
AND USE OF WASTES AND BYPRODUCTS IN 1990 BY MNR REGIONS

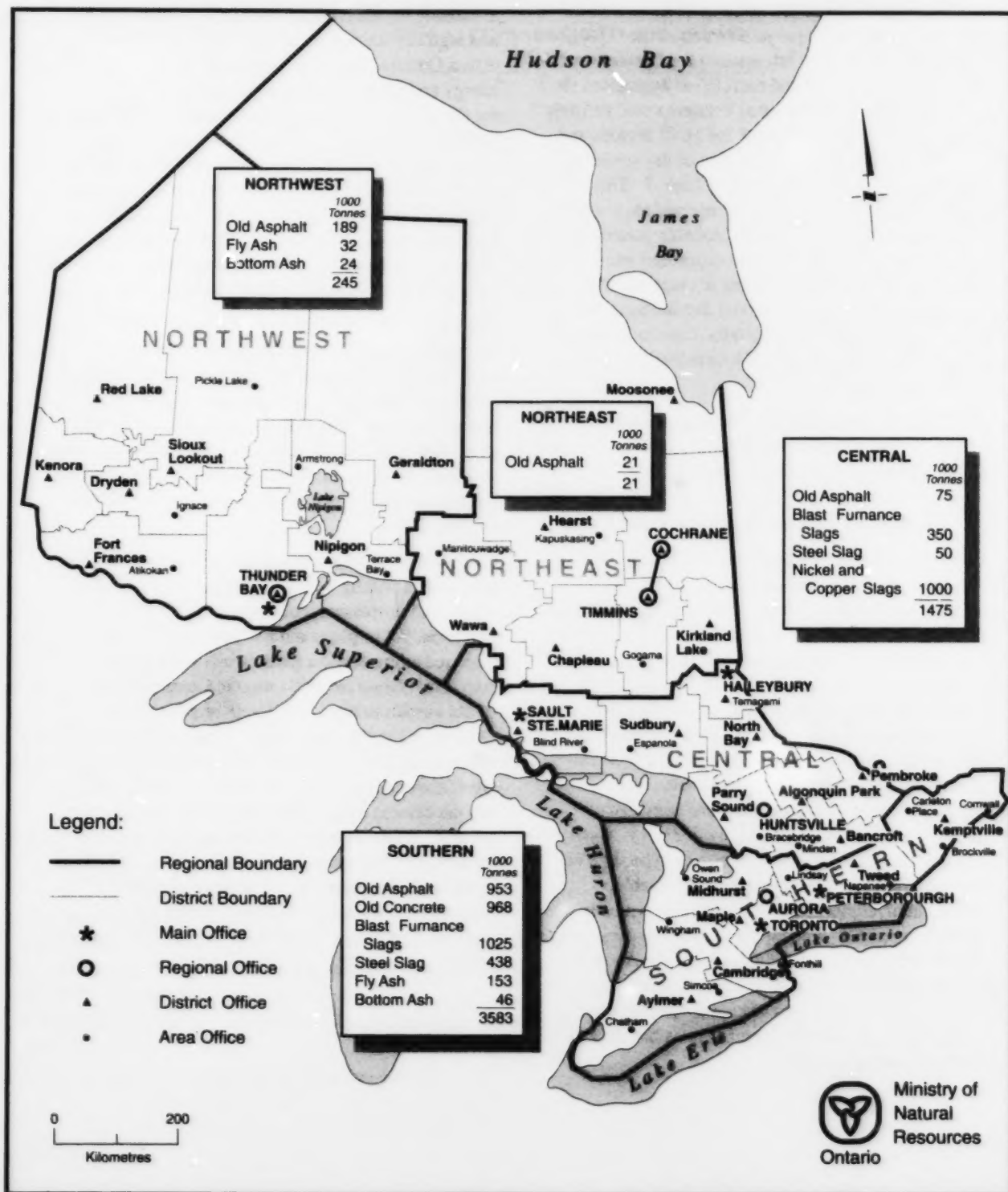


**TABLE 6 MINISTRY OF TRANSPORTATION REGIONS, DISTRICTS
AND JURISDICTIONS OF MUNICIPAL ENGINEERS**

A. REGIONS AND DISTRICTS	B. JURISDICTIONS OF MUNICIPAL ENGINEERS
REGIONS	DISTRICTS
Central Region, Toronto	Chatham Essex, Kent, Lambton
Hamilton District	London
Toronto District	Elgin, Middlesex, Haldimand-Norfolk, Oxford
Port Hope District	Stratford Huron, Perth, Waterloo, Wellington, Dufferin
	Hamilton
Eastern Region, Kingston	Brant, Niagara, Hamilton-Wentworth, Halton
Kingston District	Owen Sound
Ottawa District	Bruce, Gray, Simcoe
Bancroft District	Toronto
	Peel, York, Durham
	Toronto
	Metropolitan Toronto area
Southwestern Region, London	Port Hope
	Northumberland, Victoria and southern part of Peterborough
Chatham District	Kingston
London District	Leeds and Grenville, Prince Edward, southern parts of Frontenac,
Stratford District	Hastings, Lennox and Addington
Owen Sound District	Ottawa
	Ottawa-Carleton, Lanark, Prescott and Russell, Stormont, Dundas
	and Glengarry, and eastern parts of Renfrew
Northern Region, North Bay	Bancroft
Huntsville District	Northern parts of Frontenac, Hastings, Lennox and Addington and
North Bay District	Peterborough, western part of Renfrew and six adjoining
New Liskeard District	municipalities in Haliburton and Nipissing
Cochrane District	Huntsville
Sudbury District	Haliburton (part), District of Muskoka, and southern portion of Parry Sound
	North Bay
	Nipissing, Northern portion of Parry Sound and seven adjoining municipalities
Northwestern Region, Thunder Bay	New Liskeard
Sault Ste. Marie District	Timiskaming and Cochrane District south part and Sudbury district north part
Thunder Bay District	
Kenora District	Cochrane
	Part of Cochrane north
	Sudbury
	Sudbury, Manitoulin and small part of Algoma (east)
	Sault Ste. Marie
	Algoma, and small portions of Sudbury and Thunder Bay
	Thunder Bay
	Thunder Bay and Atikokan area of Rainy River District and part of Kenora
	Kenora
	Kenora District and Rainy River

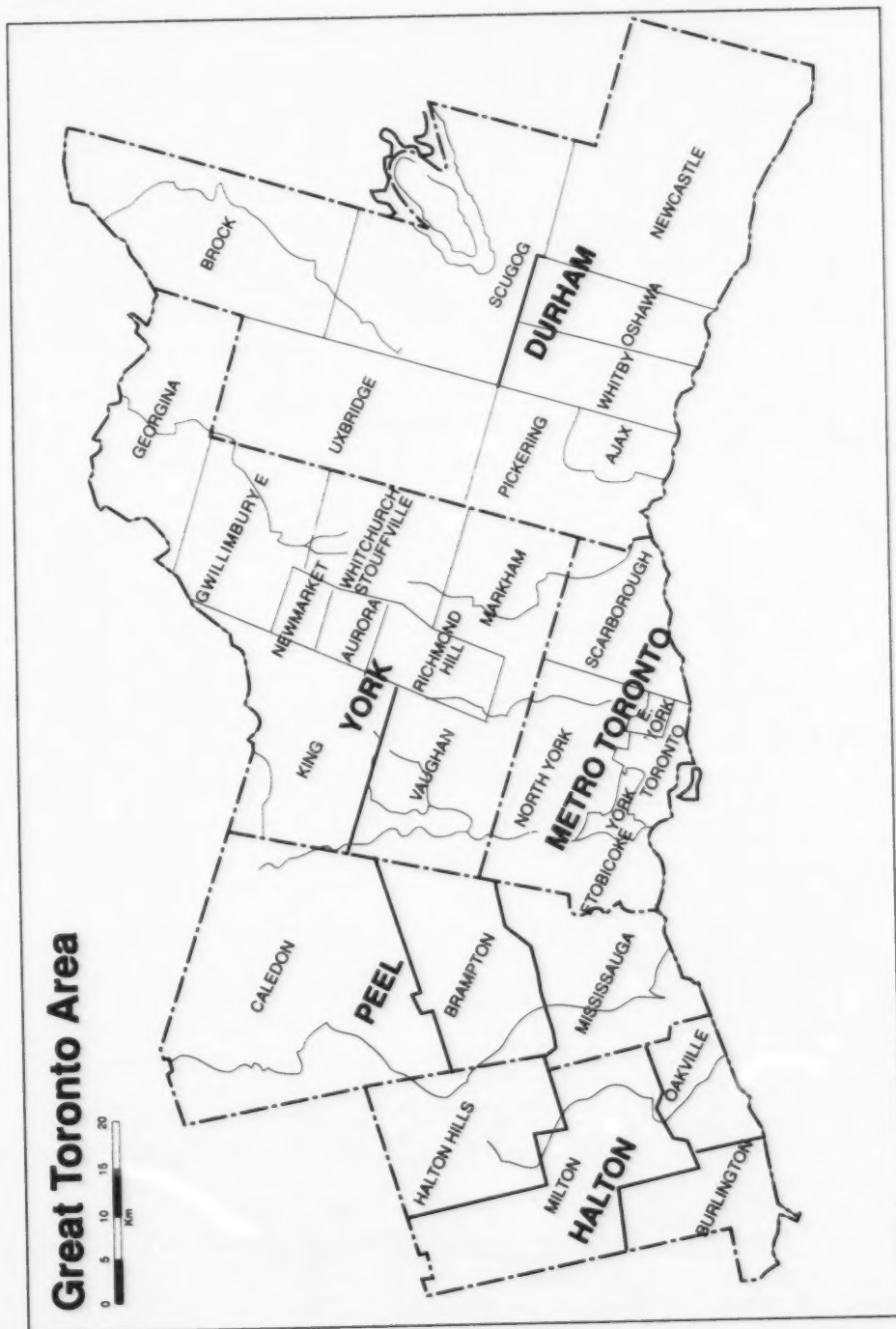


FIGURE 3 Greater Toronto Area (GTA)

**TABLE 7 ONTARIO WASTES AND BYPRODUCTS USE RANKING, 1990
USE, AND AVAILABILITY**

WASTES AND BYPRODUCTS	RANKING**		1990 USE	AVAILABILITY	
	BULK	CEMENTITIOUS		PRODUCTION/ STOCKPILED YEAR 1000 TONNES	
Old Asphalt (W)*	1,C***	(C)	1,364	?	1,493
Old Concrete (W)	2,C		968	?	776
Blast Furnace Slags (B)	3,C	3,C	1,375	1,650	>25,000
Air-Cooled (B)	3c,C		575	550	>25,000
Pelletized (B)	3d,C	3a,C	700	700	0
Granulated (B)	3e,C	3b,C	100	400	450
Steel Slag (B)	4,C		488	638	5,000
Nickel and Copper Slags (B)	5,C,P	5,P	1,000	1,700	2,900
Air-cooled (B)	5a,C		1,000	1,000	400
Granulated (B)	5c,P	5b,P	0	700	2,500
Fly Ash (W)	6,C	6,C	195	924	>12,800
Kiln Dusts (W)		7,C	?	204	>740
Cement (W)	7b,C		?	132	>600
Lime (W)	7a,C		?	72	140
Bottom Ash (W)	8,C		70	120	0
Foundry Sand (W)	9,C		?	267	?
Mining Waste Rock (W)	10,C		?	≈2,500	>196,000
Demolition Waste (W)			?	300	
Waste Shingles (W)	Not Ranked		Minor	Estimated { 200	Not Determined
Waste Tires (W)			Minor	100	
Waste Glass (W)			Minor	100	
Miscellaneous, Small Quantity (W)			Minor	?	
Miscellaneous, Future Potential (W)			-	-	

*W - waste B - byproduct

**Bulk - uses such as: aggregates; ballast; engineered fill; filler; etc.

Cementitious - uses such as: blended cements; kiln feed; stabilization; etc.

***C - current P - potential. (Brackets for cementitious component related to bulk use.)

Miscellaneous, Small Quantity - waste brick; waste wood; waste plastic; waste paper; waste ceramics/refractories; lignins; resins; etc.

Miscellaneous, Future Potential - surplus sulphur; sulphate wastes; clean dredge spoil; decontaminated soil; high temperature incinerator residue; etc.

TABLE 8 MAJOR ONTARIO WASTES AND BYPRODUCTS 1990 USE AND AVAILABILITY BY MNR REGIONS* AND GTA**

USE/PRODUCTION PER YEAR/STOCKPILED 1000 TONNES

WASTES AND BYPRODUCTS	SOUTHERN	CENTRAL	NORTHEAST	NORTHWEST	GTA
Old Asphalt	953/***/1384	75/***/81	21/***/2	189/***/26	534/***/788
Old Concrete	968/***/775	-	0/***/2	-	783/***/519
Blast Furnace Slags	1025/1000/0	350/650/>25000	-	-	-
Air-Cooled	325/300/0	250/250/>25000	-	-	-
Pelletized	700/700/0	-	-	-	-
Granulated	-	100/400/450	-	-	-
Steel Slag	438/433/0	50/200/>5000	-	-	45/***/?
Nickel and Copper Slags	-	1000/1550/2900	0/150/0	-	-
Air-Cooled	-	1000/1000/400	-	-	-
Granulated	-	0/550/2500	0/150/0	-	-
Fly Ash	153/764/>12000	-	-	32/160/800	128/128/0
Kiln dusts	?/183/>670	0/21/70	-	-	0/25/>200
Cement	?/132/>600	-	-	-	0/25/>200
Lime	?/51/70	0/21/70	-	-	-
Bottom Ash	46/96/0	-	-	24/24/0	22/22/0
Foundry Sand	9/267/?	-	-	-	0/3/?
Mine Waste Rock	?/340/43	?/60/112000	?/1900/83000	?/216/775	0/0/0

*Reorganized Ministry of Natural Resources Regions, Figure 2

**Greater Toronto Area - Halton; Peel; Metro Toronto; York; and Durham Regions, Figure 3. (1990 use is given in terms of production point so that actual use of several wastes and byproducts in GTA is not given.)

***Annual production variable or not known, but typically similar to 1990 use.

NOTES

Old Asphalt - Additional 126,625 tonnes of RAP used in 1990 in portable plants RHM.

Blast Furnace Slags - Use (Southern) includes 25,000 tonnes from United States.

Steel Slag - Use (Great Lakes) does not include 150,000 tonnes exported to United States.

Bottom Ash - Fly ash and bottom ash from Nanticoke is currently collected in lagoons so not readily available for use.

Kiln Dusts - Some kiln dusts are being used for stabilization, but small use in 1990 not determined.

Foundry Sand - Some waste foundry sand is being used in hot mix production.

Mine Waste Rock - Trap rock (Southern) included, but normally considered an aggregate. Trap rock is used in Southern Ontario and some mine waste rock is used locally, particularly during mine development work.

3.1.1 Major Sources, Availability and Uses

Old asphalt (RAP) is generated from most flexible pavement reconstruction (full depth removal) and major maintenance/ resurfacing projects (surface milling). The RAP is then stockpiled for processing and use in RHM or as granular base. For MTO projects, any RAP generation is generally balanced with RAP use in project RHM, and/or sometimes mixing with granular.

For non-MTO projects, typically in urban areas, the RAP is accumulated in stockpiles at hot-mix plants for processing and use. The increasing dumping fees at landfills (Metro Toronto in 1991 charging \$150 per tonne), and the ban on recyclable materials such as clean fill, old asphalt, old concrete and rubble at

landfills (Metro Toronto Policy as of July 1, 1991 for instance) will undoubtedly result in more available RAP in urban areas (Metro, 1991a).

A listing of active asphalt plants was developed with assistance of OHMPA and hot-mix industry contacts. This listing was then used through a telephone survey conducted during the first quarter of 1991 to determine the number of asphalt plants undertaking recycling. The amount of RAP used in RHM and/or granular base in 1990 and currently stockpiled was determined for each plant. As most old reclaimed concrete material (RCM) processing is done at asphalt plant sites, similar information for RCM was obtained. The RAP inventory information summarized by MNR region/district (and GTA) and MTO region/district (and

GTA) is given in Tables 9A and 9B respectively. (Summarized data and/or producer codes are used throughout the inventory tables to maintain confidentiality). It should be noted that this appears to be the first comprehensive listing of Ontario asphalt plants (some 144) and hot-mix plants recycling (some 92).

The 1990 RAP use in RHM and granular base of 1.36 million tonnes from the inventory is close to the MTO 1990 estimate of 1.2 million tonnes including about 300,000 tonnes in MTO projects (Katona, 1991). It is estimated that about 13 million tonnes of hot-mix asphalt (HMA) was used in Ontario in 1990. RAP contributed some 10 percent of the aggregates and asphalt cement used. RAP use in the GTA was 39.0 percent of the Ontario 1990 RAP use, and RAP stockpiled in the GTA is 52.8 percent of Ontario's 1.49 million tonnes stockpiled.

As indicated in Tables 9A and 9B, the major use (89.5 percent) of processed RAP is in RHM, which is considered as current standard asphalt technology. Some 10.5 percent is used in granular base, which as a developing use unfortunately does not recover the aged asphalt cement. Recycling has become an important component of the paving industry and it is critical that the necessary asphalt technology be adopted to ensure that the desired RHM quality is achieved. The RAP is combined with new aggregates and new asphalt cement in a batch or drum, or combined in a drum-batch hot-mix plant to produce RHM (FHWA, 1987). The new asphalt cement added is typically a higher penetration grade in order to soften the aged asphalt cement in the RAP. For batch plants, the amount of RAP incorporated is typically limited to 10 to 20 percent to ensure adequate drying and heat transfer in the pugmill from superheated aggregate. The need to soften the aged asphalt cement and to control potential emissions (blue smoke), limits the amount of RAP that can be currently be incorporated in drum plants to between 40 to 60 percent.

The consistent production of quality RHM incorporating a high RAP content (40 percent and greater) requires: representative Marshall mix design; proper RAP processing, stockpiling and proportioning; selection of an appropriate new asphalt cement with penetration to ensure a satisfactory in-place penetration (Absorption recovery); consistent hot-mix plant operation to control moisture content, mix uniformity and adhere to

environmental regulations; and producer quality control/agency quality assurance procedures (Earl and Emery, 1987). Generally, the need for special aggregate characteristics in surface course mixes (for example, good frictional properties) and high stability (heavy duty) binder course mixes (100 percent crushed aggregates for instance) limits the major use of RAP to binder course mixes, with some use in low annual average daily traffic (AADT) surface course mixes. The sequence of RAP use in RHM is shown on the cover and in more detail in Photographs 1 to 5.

Photograph 6 shows a typical old concrete (RCM) processing operation at a hot-mix plant location.

It is very easy to make provision for RAP use in a project by simply referencing the quality requirements of a conventional mix. For example, the Metro Transportation

MT 701 Specification (Metro, 1991b) states "The use of RAP (Reclaimed Asphalt Pavement) for the contract will only be permitted in HL 8 mix, with a replacement limit of 40% (recycling 'ratio' limit of 40/60, RAP to new aggregate). Any RAP incorporated shall have the necessary gradation, physical properties and asphalt cement content consistency to result in an HL 8 (RAP) mix meeting all the requirements for HL 8 mix." Metro HL 8 mix is a conventional binder course asphalt mix.

The use of processed RAP as part of granular base and subbase has been developed by the MTO and some agencies in the GTA, typically limiting RAP contents to 30 percent, and between 15 to 20 percent respectively. The MTO has found the engineering properties to be satisfactory, and are evaluating increasing RAP use to 40 percent in granular material, mixed in-place RAP with granular and RAP use in embankments (Hanks and Magni, 1989; Katona, 1991). MTO Special Provisions for these RAP uses with granular material are listed in Appendix B.

The inventory data in Tables 9A and 9B, and the discussion on processed RAP use in RHM and granular base, do not include the growing use of new technology for hot and cold in-place recycling of asphalt pavements in Ontario shown in Photographs 7 to 9 (Emery and Terao, 1990; Bradbury, Kazmierowski, Cheng and Raymond, 1991). These recycling methods are described in the pavement rehabilitation section of Appendix B and are covered by MTO Special Provisions. For 1990, it is estimated that the equivalent of about 60,000 tonnes of old asphalt.

TABLE 9 ONTARIO USE OF OLD ASPHALT

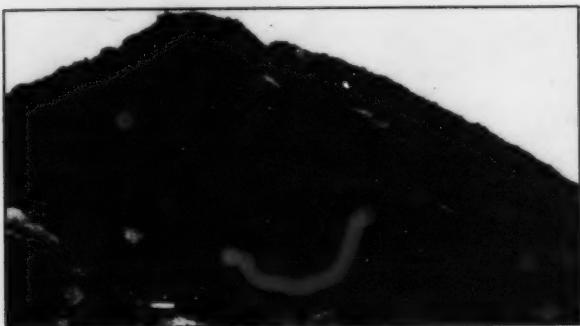
TABLE 9A ONTARIO USE OF OLD ASPHALT (RAP) IN 1990 BY MNR REGIONS/DISTRICTS

MNR REGION/DISTRICT	NUMBER OF ASPHALT PLANTS	NUMBER OF ASPHALT PLANTS RECYCLING	RAP USE		RAP STOCKPILED TONNES
			GRANULAR TONNES	RHM TONNES	
Greater Toronto Area	36	26	16,300	517,300	788,250
Southern					
Maple	35	25	20,300	510,100	782,250
Aylmer	14	8	18,500	81,600	143,800
Cambridge	31	26	35,800	164,500	184,700
Kemptville	13	7	2,000	75,000	185,000
Midhurst	11	2	0	24,500	42,500
Tweed	6	4	3,750	17,000	45,500
	110	72	80,350	872,700	1,383,750
Central					
Sault Ste. Marie	4	2	0	5,600	35,000
Sudbury	2	2	0	52,500	7,350
North Bay	3	1	0	-	4,000
Parry Sound	3	2	2,500	7,500	15,000
Bancroft	0	-	-	-	-
Pembroke	3	1	0	7,000	20,100
	15	8	2,500	72,600	81,450
Northeast	5	1	5,000	16,000	2,000
Northwest	5	4	55,000	133,700	25,500
Portable Plants used in 1990	9	7	0	126,625	0
TOTAL	144	92	142,850	1,221,625	1,492,700

TABLE 9B ONTARIO USE OF OLD ASPHALT (RAP) IN 1990 BY MTO REGIONS/DISTRICTS

MTO REGION/DISTRICT	NUMBER OF ASPHALT PLANTS	NUMBER OF ASPHALT PLANTS RECYCLING	RAP USE		RAP STOCKPILED TONNES
			GRANULAR TONNES	RHM TONNES	
Greater Toronto Area	36	26	16,300	517,300	788,250
Central					
Toronto	35	25	20,300	504,800	773,250
Hamilton	19	16	20,000	119,000	101,500
Port Hope	3	3	3,750	48,000	32,500
	57	44	44,050	628,600	907,250
South Western					
Chatham	8	3	17,500	20,000	73,800
London	7	5	1,000	61,600	70,000
Owen Sound	8	2	0	24,500	42,500
Stratford	14	11	15,800	58,000	98,200
	37	21	34,300	164,100	284,500
Eastern	19	9	2,000	87,000	218,000
Northern	5	4	55,000	133,700	28,350
Northwestern	9	7	0	126,625	60,500
Portable Plants used in 1990	9	7	0	126,625	0
TOTAL	144	92	142,850	1,221,625	1,492,700

pavement was recycled in-place. The use of both hot and cold in-place recycling in Ontario will undoubtedly grow as more contractors obtain the necessary equipment, desired quality levels are achieved, agencies become familiar with the processes and favourable economics are demonstrated.



PHOTOGRAPH 1 LARGE PILE OF OLD ASPHALT PAVEMENT (RAP) WITH SMALL PILE OF OLD CONCRETE (RCM) TO LEFT, DOWNSVIEW.

3.1.2 Storage and Processing

RAP is essentially inert from an environmental viewpoint as determined from leachate testing (Bancsi, Benedek, Emery and Lawrence, 1980; Kriech, 1991; Parker, 1991) and supported by current MOE policy (MOE, 1988). However, MOE and MTO require care with RAP storage and fill near water sources (MTO Special Provision No. 199F30) (Katona, 1991). RAP from construction sites is typically stockpiled at hot-mix plants (Photograph 1), with any deleterious material removed, prior to processing for use in RHM with a wide range of fixed and portable plants (FHWA, 1987). A typical RAP processing plant (Photograph 2) consists of a primary crusher, screening units, secondary crusher, conveyors and stacker, with the crushing operation a closed loop to achieve the desired processed RAP gradation. It is important for RHM use that the RAP be consistent and kept as coarse as possible with the fines ($-75 \mu\text{m}$) being minimized (Earl and Emery, 1987).

3.1.3 Technical, Environmental and Economic Factors

The use of RAP in RHM and granular base/subbase material is now well established in Ontario, and can be considered as conventional technology in the hot-mix industry. However, there is a wide range of company expertise in the recycling of RAP and RCM across the province. RCM is included in the discussion here, as

RCM is often processed at the same locations as RAP. There is greater awareness of the economic benefits of RAP and RCM recycling in the GTA and Southern Ontario. Of course, this is coupled with the growing availability of RAP and RCM, associated with large stockpiles resulting from landfill constraints. However, the actual number of companies involved with significant RAP and RCM recycling is still small. For example, about 50 percent of the RAP and RCM recycling in the GTA is carried out by only six companies out of 33, the remaining companies recycling relatively small amounts.

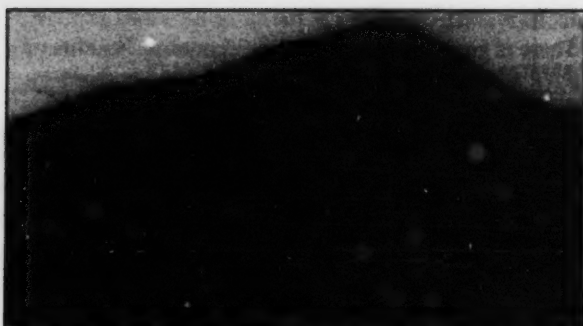
Outside of the GTA and Southern Ontario, most RAP recycling is associated with MTO projects and there is little RCM available for recycling. The reasons given by companies during the survey for not recycling RAP and/or RCM, in decreasing order of frequency are:

1. not set up for RHM production as RAP not available, no RHM market and/or previous poor experience with RHM, with several considering setting up;
2. RHM production an inconvenience and/or did not know how to set up; and
3. would like to be set up for RHM production and/or RCM recycling, but local user agencies not cooperative.



PHOTOGRAPH 2 OLD ASPHALT PAVEMENT (RAP) PROCESSING PLANT (CRUSHING, SCREENING AND STOCKPILING) FOR RAP USE IN RECYCLED HOT MIX (RHM), DOWNSVIEW.

It is considered that these technical impediments to recycling RAP and RCM will be resolved in the short term by: with the wider use of portable RAP processing equipment (FHWA, 1987); hot-mix industry and MTO activities indicating show RHM quality equivalence to new hot mix; availability of enough RAP and RCM at more locations due to fill and landfill constraints; and centralized collection of RAP and RCM.



PHOTOGRAPH 3 STOCKPILE OF PROCESSED RAP FOR USE IN RHM, DOWNSVIEW. PROCESSED RAP CONTAINS BOTH AGGREGATE AND AGED ASPHALT CEMENT.

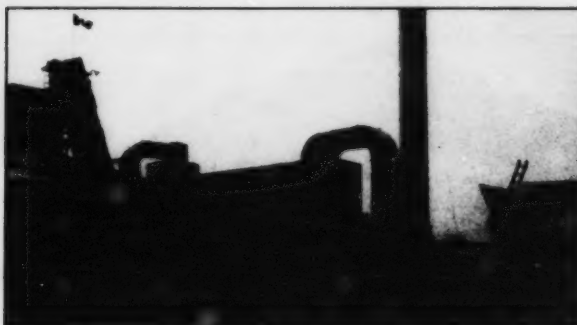
The positive environmental features of materials, energy and landfill space conservation associated with RAP and RCM recycling are clear. However, there are two potential environmental constraints of concern: gaseous emissions (blue smoke) control during RHM production; and the leachability of RAP. With RAP incorporated up to 50 percent in RHM (typical current upward limit for provinces and states), there does not appear to be a blue smoke problem for hot-mix plants with appropriate heating/ mixing systems (Thompson and Haas, 1991) and effective dust control systems (for example, using best available technology baghouses).



PHOTOGRAPH 4 STOCKPILE OF CONVENTIONAL AGGREGATE FOR USE IN HOT MIX, MILTON. RAP USE IN RHM REPLACES BOTH AGGREGATE AND ASPHALT CEMENT.

This should remain the case under MOE's proposed Clean Air Program. Some agencies have recently raised concerns about the possible environmental impact of RHM with low addition level asbestos fibre use in some HMA up to about twenty years ago. While the technical data (Bancsi, Benedek, Emery and Lawrence, 1980; Kriech, 1991; Parker, 1991) indicates that RAP is a non-leachable material and the MOE does not

consider RAP to be a waste (MOE, 1988), the MOE and MTO are still concerned with the RAP leachability issue (Katona, 1991). It is important that the question of RAP leachability be technically resolved in the Ontario context.



PHOTOGRAPH 5 ASPHALT BATCH PLANT EQUIPPED TO USE RAP (ABOUT 25 PERCENT) IN RHM WITH RAP FEED BIN TO RIGHT AND CONVEYOR TO PLANT MIXER, DOWNSVIEW.

The economics of RAP and RCM recycling are obviously favourable, given the increasing hot-mix industry interest. This can be shown for RHM incorporating various RAP percentages and typical materials prices in the GTA based on the inventory discussions with hot-mix producers:

Typical Material Prices in GTA

Hot-mix aggregate at plant	\$11 per tonne (average for coarse aggregate, screenings and asphalt sand)
Asphalt cement at plant	\$175 per tonne
Processed RAP in stockpile	\$6 per tonne (cost to process and stockpile)

Assumptions for Cost Analysis

RHM to meet HL 8 (HMA binder course) specifications
RAP contains 4.0 percent aged asphalt cement
Production costs for RHM and HMA the same
RHM to contain 5.0 percent asphalt cement

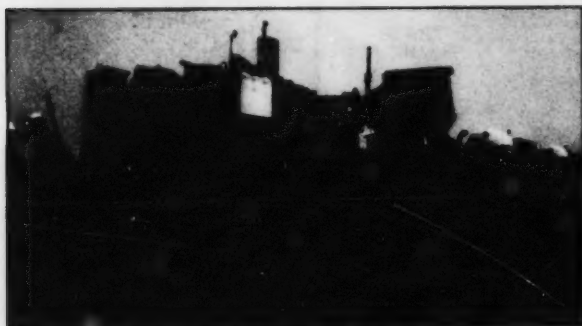
Materials Cost for HMA and RHM

	RHM			
	HL 8	10% RAP	20% RAP	40% RAP
RAP		\$0.57	\$1.15	\$2.32
New Aggregates	\$10.45	9.44	8.43	6.37
New Asphalt Cement	8.75	8.08	7.40	6.06
Total Materials Cost	\$19.20	\$18.09	\$16.98	\$14.75
'Saving' in Materials Costs		\$1.11	\$2.22	\$4.45
Percent Savings		5.8%	11.6%	23.2%



PHOTOGRAPH 6 OLD CONCRETE (RCM) PROCESSING PLANT (CRUSHING AND SCREENING) TO PRODUCE GRANULAR BASE (NOTE REMOVED REINFORCING STEEL), DOWNSVIEW.

The actual savings in materials cost for RHM at a specific hot-mix plant, as compared to the typical savings indicated, will also depend on factors such as RAP availability, cost recovery through dumping charges for RAP and RCM (currently no charge to \$30 per load), processing plant capacity, RAP moisture content, etc. Regardless, the saving of about \$1 per tonne for each 10 percent RAP incorporated in RHM appears to be currently typical for the hot-mix industry in Southern Ontario. The potential savings with RHM use obviously increase with any increase in the price of new aggregates and particularly asphalt cement.



PHOTOGRAPH 7 HOT, IN-PLACE RECYCLING OF ASPHALT PAVEMENT USING TWO PREHEATERS AND A REFORMING MACHINE, MISSISSAUGA.

3.1.4 Research and Development

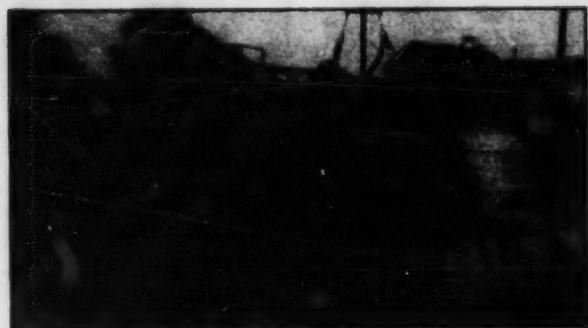
With the exception of MTO demonstration work on the use of RAP in granular base/subbase (Katona, 1991), there does not appear to be any current research and development activity with RAP or RCM in Ontario. It should be noted that RAP use as granular does not recover the aged asphalt cement. Several areas of needed research and development can be identified as

follows, along with the suggested agency or industry most likely to be in a position to take action:

1. leachability problems, if any, for representative Ontario RAP and RCM samples (MOE and MTO);
2. incorporating small RAP quantity (ten percent, New Jersey practice for instance) in all HL mix types for binder and surface course applications (MTO);
3. fine manufactured sand for RHM air voids development (MTO);
4. rutting resistance of conventional RHM, and RHM incorporating fine manufactured sand, compared to heavy duty/high stability hot mix (MTO);
5. simple, readily movable, portable plants for RAP and RCM processing (hot-mix industry);
6. simple hot-mix plant retrofit 'kits' for RHM production (hot-mix plant manufacturers); and
7. centralized collection and processing of RAP and RCM in rural areas (MNR).

3.1.5 Impediments to Increased Use

The major impediment to more use of RHM and cold and hot in-place recycling is the lack of standard specifications for non-MTO projects; MTO uses OPSS 1149 and other special provisions. The Ontario Provincial Standards Pavement Committee may be requested to provide full OPSS coverage of RHM, RCM granular, and cold and hot in-place recycling as soon as possible. A draft Ontario Provincial Standards specification for RHM is currently being reviewed by agencies and the paving industry and is certainly an important step in providing full OPSS recycling coverage.



PHOTOGRAPH 8 FULL DEPTH COLD RECYCLING OF ASPHALT PAVEMENT WITH GRANULAR BASE (NO EMULSIFIED ASPHALT ADDITION), OAKVILLE.

TABLE 10 ONTARIO USE OF OLD CONCRETE

TABLE 10A ONTARIO USE OF OLD CONCRETE (RCM) IN 1990 BY MNR REGIONS/DISTRICTS

MNR REGION/DISTRICT	NUMBER OF ASPHALT PLANTS	NUMBER OF LOCATIONS RECYCLING	RCM USE GRANULAR TONNES	RCM STOCKPILED TONNES
Greater Toronto Area	36	19	783,300	518,800
Southern				
Maple	35	19	783,300	518,800
Aylmer	14	3	74,000	79,000
Cambridge	31	10	22,250	56,250
Kemptville	13	3	63,600	25,750
Midhurst	11	1	10,000	15,000
Tweed	6	0	0	1,500
	11	36	953,150	696,300
Central				
Sault Ste. Marie	4	0	0	0
Sudbury	2	0	0	0
North Bay	3	0	0	0
Parry Sound	3	0	0	0
Bancroft	0	-	-	-
Pembroke	3	0	0	0
	15	0	0	0
Northeast	5	0	0	1,500
Northwest	5	0	0	0
Other Operations*	-	4	15,000	78,500
TOTAL	135	37	968,150	776,300

*Hamilton area general contractors and City of Hamilton Public Works Department.



PHOTOGRAPH 9 COLD, IN-PLACE RECYCLING OF ASPHALT PAVEMENT USING A MILLING MACHINE, CRUSHER, MIXER (EMULSIFIED ASPHALT ADDITION) AND PAVER TRAIN, MARKHAM.

3.1.6 Comment

The use of reclaimed old asphalt pavement (RAP) has been described in some detail as RAP is currently the waste of most significance to aggregates conservation in Ontario. This aggregates conservation is, of course, coupled with asphalt cement and landfill space conservation. The growing acceptance and use of RAP provides an important role model for the utilization of other wastes and byproducts in construction.

The use of RAP and RCM for simple fill applications has not been considered as this is considered to be more a form of disposal, rather than a beneficial use with aggregates conservation.

TABLE 10B ONTARIO USE OF OLD CONCRETE (RCM) IN 1990 BY MTO REGIONS/DISTRICTS

MTO REGION/DISTRICT	NUMBER OF ASPHALT PLANTS	NUMBER OF LOCATIONS RECYCLING	RCM USE GRANULAR TONNES	RCM STOCKPILED TONNES
Greater Toronto Area	36	20	783,300	518,800
Central				
Toronto	35	19	783,300	516,800
Hamilton	19	12	24,250	29,250
Port Hope	31	10	-	1,500
	11	36	805,550	547,550
Southwestern				
Chatham	8	2	65,000	56,000
London	7	1	9,000	23,000
Owen Sound	8	1	10,000	15,000
Stratford	14	0	-	29,000
	37	4	84,000	123,000
Eastern	19	3	63,600	25,750
Northern	14	0	-	1,500
Northwestern	8	0	-	0
Other Operations*	-	4	15,000	78,500
TOTAL	135	37	968,150	776,300

*Hamilton area general contractors and City of Hamilton Public Works Department.

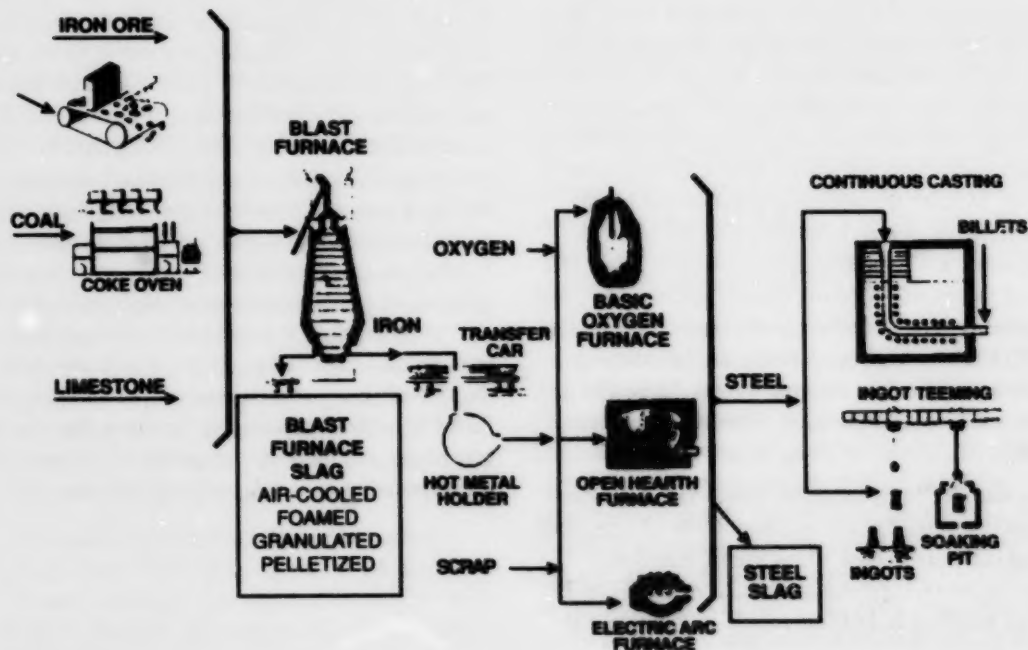


FIGURE 4 FLOW DIAGRAM OF IRON AND STEEL PRODUCTION SHOWING BYPRODUCT BLAST FURNACE AND STEEL SLAGS (Adapted from American Iron and Steel Institute).

3.2 OLD CONCRETE

The use of processed, reclaimed old concrete* (RCM) for granular material in Ontario tends to parallel the use of RAP in RHM. RCM is generated through the demolition of concrete elements of roads, runways and structures, mostly in urban areas. As with RAP, the GTA again leads the way with the use of RCM. With landfill restrictions and dumping fees, the RCM is typically processed and used on site (site demolition waste processing), hauled to specific clean fill applications such as shore protection, and/or stockpiled for processing and use as granular, typically at hot-mix plant sites.

After crushing, reinforcing steel removal and screening as shown in Photograph 6, the processed RCM can be used as granular material, aggregate in hot-mix asphalt (HMA) or aggregate in portland cement concrete (PCC) (Clifton, Brown and Frohnsdorff, 1977; Gutt and Nixon, 1978). Processed RCM, used as coarse aggregate in concrete, has a high absorption and generally yields concrete of lower strength at equal water/cement ratio and slump than conventional aggregates. If the fine crushed RCM is used, the workability decreases. For concrete use, the sulphate (old plaster for instance), chloride and reactive aggregates content of the RCM must be strictly controlled (Puckman, Heinrichsen and Hansen, 1988). For these reasons, the use of processed RCM has been mainly in granular base in urban areas where transportation costs favour such processed RCM use. Also, most agencies allow some RAP (up to 30 percent by MTO** for instance) in processed RCM granular material, which is fortunate, as RCM often contains some RAP and fine aggregate. It is likely that the use of processed RCM in concrete in Ontario, if any, will require significant technical development activities and MTO/CSA involvement (Puckman, Heinrichsen and Hansen, 1988). Use in cement treated base (for example, some econocrete uses) appears to be more promising.

Old concrete (RCM) is available from road and runway reconstruction projects, and the demolition of structures, involving concrete in base, slabs, curbs, sidewalks, foundations, piers, caps, columns, etc. About 70 to 75 percent of building demolition rubble is concrete, but

the quantity is generally small except for large demolition projects (for example, Skydome site preparation). For Ontario, RCM is available in larger quantities in urban areas where concrete and composite pavements are used such as Metro Toronto, Hamilton, St. Catharines, Windsor and Ottawa. RCM is generally stockpiled at hot-mix plant sites for reprocessing and use by road building contractors***. Some ready-mix concrete waste is also taken to RCM stockpiles. This may decrease using stabilization additives in the ready-mix industry.

With the assistance of OHMPA and Ontario Road Builders Association (ORBA) contacts, the amount of RCM used in 1990 and currently stockpiled was determined in parallel with the RAP inventory. This RCM inventory information summarized by both MNR region/district, MTO region/district and GTA is given in Tables 10A and 10B respectively. Reprocessed RCM use as granular material in 1990 was 968,150 tonnes with 776,300 tonnes of RCM stockpiled. RCM use as granular material in the GTA was 80.9 percent of the Ontario 1990 RCM use, and RCM stockpiled in the GTA is 89.7 percent of the Ontario RCM stockpiled.

From an economic point of view, the price of processed RCM for use as granular base (about \$8.00 per tonne at the plant) is more than crushed stone FOB the quarry. This is due to the relatively small quantities involved and more labour-intensive nature of the operation such as removing reinforcing steel (Photograph 6). With the processed RCM generally closer to urban project areas, there is a potential overall savings of typically 5 to 10 percent in using reprocessed RCM as granular material. In addition, contractors like the way processed RCM locks up in granular base and its high yield. However, care must be taken to avoid undesirable particle size segregation with crushed RCM. The likely increase in RCM availability and introduction of dumping charges for RCM within landfills, will improve the overall economics and increase the quality of processed RCM use as granular material, particularly in the GTA.

*Concrete refers to portland cement concrete (PCC) throughout.

**See Appendix B for MTO Special Provision on processed RCM use as granular material.

***See demolition wastes section for site processing and use of RCM from demolition work.

There do not appear to be any impediments to the use of processed RCM as granular base by MTO and urban agencies but, as with recycling old asphalt, it would be helpful if there was an OPSS for referencing such use (Ontario Provincial Standards Pavement Committee). Obviously, care must be taken to not incorporate deleterious or leachate sensitive material in RCM. Recent leachate testing of concrete pavement surface grindings from several American projects indicated no environmental problems (IGGA, 1990). There are technical constraints on RCM use as concrete aggregate. Since research and development on other RCM uses is not recommended at this time, all of the available processed RCM can be used up in granular base/subbase.

3.3 BLAST FURNACE SLAG

Of the wastes and byproducts of interest for Ontario aggregates conservation in Tables 5 and 7, blast furnace slag* is the easiest to deal with technically, as aggregate applications are covered by conventional aggregate specifications** and cementitious applications are covered in detail by CSA standards**. For this reason, processed air-cooled blast furnace slag is generally considered to be a construction aggregate, rather than a byproduct (Emery, 1982; Owens, 1988). The only significant questions for Ontario are: how much blast furnace slag will be available as granulated or suitably pelletized for slag cement use; and the continuing viability or size of some Canadian steel companies.

Blast furnace slag results from the fusion of fluxing stone with coke ash and the siliceous and aluminous residues remaining after the reduction and separation of iron from the ore, as shown schematically in Figure 4. The blast furnace operation is a continuous process with the carefully controlled raw materials being fed in (burden) and the uniform products, molten iron and liquid slag (about 20 percent by mass of iron production), being drawn off at regular intervals. Selective cooling of the liquid slag results in four distinct types of blast furnace slag:

1. air-cooled slag (solidification under ambient conditions), which finds extensive use in conventional aggregate applications (by far the major type used generally, and until recently in Ontario);
2. expanded or foamed (solidified with controlled quantities of water, air and/or steam), which is

mainly used as lightweight aggregate (minor type, none produced in Ontario);

3. pelletized slag (solidified by water and air-quenching in conjunction with a spinning drum), which is used both as lightweight aggregate and in slag cement manufacture when suitably vitrified (process developed in Hamilton by National Slag Limited and is now the major type produced in Ontario); and
4. granulated slag (solidified by quick water-quenching to a glassy state), which is mainly used in slag cement manufacture (its use is now quickly developing in Ontario).

Air-cooled blast furnace slag is used as aggregate in granular base, hot-mix asphalt (HMA) and portland cement concrete (PCC). The three prime cementitious applications for glassy blast furnace slag (granulated or suitably pelletized) are: portland blast furnace slag cements produced by intergrinding various portions of glassy slag with portland cement clinker; super-sulphated cement produced by intergrinding glassy slag, anhydrite and portland cement; and ground granulated blast furnace slag (GGBFS) for blending or addition at the mixer as partial portland cement replacement. The GGBFS route, as covered by CSA Standards (CSA-A362, A23.5 and A363), is generally being followed in Ontario and appears to be the preferred approach for new slag cement production world wide (Emery, 1987b; Hooton and Emery, 1990). Blast furnace slag tends to be quite consistent and favourable in composition, as shown by the typical compositions of ferrous and nonferrous slags in Table 11. This has nurtured its use in aggregate and cementitious applications, as compared to other slags (Emery, 1987b).

Blast furnace slag is produced and processed at three locations in Ontario (Hamilton, Lake Erie and Sault Ste. Marie) as indicated by the use, production and stockpile inventory data in Table 12. A small amount is imported from Detroit for use in hot-mix asphalt. All of the current blast furnace slag production is used as aggregate, or in slag cement manufacture (mainly GGBFS) as indicated by the production data in Table 13, with the exception of extra granulated slag produced at Algoma (Reiss Lime). This extra granulated slag could be used for slag cement manufacture by Reiss Lime at their Spragge plant and by others as GGBFS markets develop, or granular applications. There is also

*Blast furnace slag is often referred to as iron blast furnace slag to distinguish it from other blast furnace slag types such as lead blast furnace slag.

**See Appendix B for typical specifications for aggregate and cementitious uses.

TABLE 11 TYPICAL COMPOSITIONS OF FERROUS AND NONFERROUS SLAGS

CONSTITUENT	IRON BLAST FURNACE SLAG* PERCENT								STEEL** SLAG	NICKEL*** SLAG	COPPER*** SLAG
	1949		1957		1968		1985		BOF	GRANULATED	AIR COOLED
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE			
Calcium Oxide (CaO)	41	34-48	41	31-47	39	32-44	39	34-43	41.3	3.2	1.4
Silicon Dioxide (SiO ₂)	36	31-45	36	31-44	36	32-40	36	27-38	15.6	39.8	41.0
Aluminum Oxide (Al ₂ O ₃)	13	10-17	13	8-18	12	8-20	10	7-12	2.2	7.3	4.7
Magnesium Oxide (MgO)	7	1-15	7	2-16	11	2-19	12	7-15	6.9	3.5	1.0
Iron (FeO or Fe ₂ O ₃)	0.5	0.1-1.0	0.5	0.2-0.9	0.4	0.2-0.9	0.5	0.2-1.6	20.0	47.3	49.5
Manganese Oxide (MnO)	0.8	0.1-1.4	0.8	0.2-2.3	0.5	0.2-2.0	0.44	0.15-0.76	8.9	0.1	0.1
Sulphur (S)	1.5	0.9-2.3	1.6	0.7-2.3	1.4	0.6-2.3	1.4	1.0-1.9	-	1.4	1.0
Other Constituents									(TiO ₂) 0.5 (Free CaO) 3.3	(Ni) 0.2	(Cu) 1.0

*From National Slag Association data: 1949 (22 sources); 1957 (29 sources); 1968 (30 sources); and 1985 (18 sources).

**Typical JEGEL data for Ontario basic oxygen furnace steel slag. Note the free CaO content.

***From JEGEL study data for CANMET.

TABLE 12 BLAST FURNACE SLAG USED (PRODUCED)* IN 1990 AND STOCKPILED

					BLAST FURNACE SLAG TYPE TONNES					
SUPPLIER	MNR		MTO		PELLETIZED		AIR-COOLED		GRANULATED	
	REGION	DISTRICT	REGION	DISTRICT	USED IN 1990	STOCKPILED	USED IN 1990	STOCKPILED	USED IN 1990	STOCKPILED
A	S	Cambridge	C	Hamilton	700,000	0	300,000	0		
B	C	Sault Ste. Marie	NW	Sault Ste. Marie	-	-	250,000	64,700 processed >25 million in mixed stockpile**	-	-
C	C	Sault Ste. Marie	NW	Sault Ste. Marie	-	-	-	-	100,000 (production 400,000)	450,000
D***	S	Cambridge	SW	Aylmer	-	-	25,000	-	-	-
TOTALS					700,000	-	575,000	64,700 processed >25 million in mixed stockpile**	100,000	450,600

*Amount used equals that produced in 1990 except as noted.

**Mixed stockpile consists of 20 million tonnes of blast furnace slag plus 5 million tonnes of blast furnace slag mixed with steel slag (=30 percent steel slag).

***American company supplying into Ontario from Detroit for HMA aggregate use; Ontario supply figures only given.

TABLE 13 ONTARIO GROUND PELLETIZED AND GRANULATED SLAG (SLAG CEMENT, GGBFS) PRODUCTION IN 1990 AND INVENTORY

SUPPLIER	MNR		MTO		GROUND IN 1990 TONNES	INVENTORY TONNES
	REGION	DISTRICT	REGION	DISTRICT		
A	C	Sault Ste. Marie	NW	Sault Ste. Marie	100,000 *	4,000
B	S	Cambridge	C	Hamilton	400,000	0
C	S	Cambridge	C	Hamilton	40,000 **	0
TOTAL					540,000	4,000

*As much as 200,000 tonnes in 1991.

**Foundry slag interground 50:50 with pelletized slag from same supplier of B. Meets same chemical and physical requirements as pelletized slag, but does not strictly meet the definition of slag cement (GGBFS).

about 25 million tonnes of air-cooled blast furnace slag in stockpiles at Algoma in Sault Ste. Marie (A.B. McLean). However, the most recent 5 million tonnes stockpiled contains some steel slag which could be deleterious for some aggregate applications.

It should be emphasized again that processed blast furnace slag is usually considered to be a conventional building material. For instance, some 36,000 tonnes of blast furnace slag from Hamilton (National Slag Limited) was used in the construction of Scotia Plaza in Toronto (as slag cement, semi-lightweight slag concrete and slag blocks, NSA, 1988). It is anticipated the remainder of Ontario's blast furnace slag (Algoma blast furnace slag) will eventually be used in aggregate and cementitious applications when slag cement (GGBFS) demand increases (particularly in Northern Ontario), and transportation/logistics permit a larger aggregates use range for the air-cooled blast furnace slag. It is important that stockpiled blast furnace slag not be contaminated. The transportation of blast furnace slag from Sault Ste. Marie to Southern Ontario demand points must also be evaluated.

The problems with steel slag usage described in the next section have resulted in the increasing use of air-cooled blast furnace slag in surface course hot mix. This HMA use requires coarse and fine aggregates that are consistent in physical characteristics and quality. Some air-cooled blast furnace slag aggregates consistency problems in HMA have been experienced recently by JEGEL and the MTO. These problems need to be resolved.

The only potential impediment to the continued use of blast furnace slag in granular materials applications is

some concern with leachates (there is often a sulphur odour and some coloration of water contacting fresh blast furnace slag) (Owens, 1988). JEGEL testing and review of the technical literature have not indicated any leachate toxicity concerns for suitably processed blast furnace slag used as granular base (or steel slag from primary steel production used in HMA). In addition, it appears that the United States EPA will continue to exclude blast furnace slag from solid waste classification, based on favourable leachate testing (Owens, 1988 and continuing discussions with Judy Owens of United States Bureau of Mines). While the amount of Ontario blast furnace slag used as granular base will undoubtedly decrease as cementitious and HMA use grows, it would be prudent to establish the leachate characteristics of representative slag samples and to develop granular materials use guidelines.

3.4 STEEL SLAG

Steel slag was an Ontario industrial byproduct of minor construction use in 1970. Some steel slag was being recycled to blast furnace burden with the remainder used as site fill or landfill. Now, steel slag aggregates find wide utilization in Southern Ontario in hot-mix asphalt (HMA)*, particularly HL 1, DFC and OFC surface course mixes requiring good frictional and stability characteristics (Emery, 1982; 1987a). There is also growing utilization of steel slag aggregates in HMA in Northern Ontario. Unfortunately, there is also now a strong possibility that Hamilton/Lake Erie steel slag aggregates will be excluded from HMA use due to significant performance problems (Metro, 1991b; Emery, 1987a).

*See Appendix B for a discussion of HMA technology.

The extensive map cracking of HMA incorporating steel slag coarse and fine aggregates in the Hamilton-Toronto use area has been investigated by JEGEL since 1986. This investigation has included both MTO and agency paving projects, and it appears that the HMA map cracking is related to Hamilton/Lake Erie steel slags produced after about 1980 when more lime materials were introduced in the steel making process. The map cracking appears to be related to deleterious soft lime and/or lime-oxide agglomerations in the steel slag coarse and fine aggregates. Other mechanisms may also be involved or may contribute to the problem. For instance, moisture remaining in steel slag aggregates during HMA production certainly contributes to the poor performance. The steel slag use, production and stockpile inventory data given in Table 14, with some 488,500 tonnes used in HMA in 1990 and a large stockpile at Algoma in Sault Ste. Marie, indicates the importance of resolving the map-cracking performance problem. Factors such as the cause(s) of the performance problems, steel slag modification(s), if necessary, steel slag processing, specification development, steel slag HMA composition changes, etc. must be considered to preserve and extend this important byproduct aggregate use. This will undoubtedly require significant steel industry, steel slag processing company and steel slag aggregates marketing company effort, and perhaps Ontario government (MTO and MNR) technical and financial

assistance. The various steelmaking processes shown in Figure 4 (no open hearths left in Ontario) generally introduce important restrictions in the use of steel slags compared to blast furnace slags. Steel slags have a high bulk density and potential expansive nature with volume changes up to 10 percent attributable to the hydration of calcium and magnesium oxides (Table 11). Blast furnace slags have a relatively low bulk density and are stable. Since serious damage may result from indiscriminate use of steel slags in confined applications, potential long-term volume changes must be checked before such usage. Obviously, steel slags should not be used in concrete (PCC) since expansion will result in rapid destruction of the concrete.

The use of steel slag aggregates in HMA has developed as a suitable aggregate use in a number of world-wide steel production areas, and was started in the Hamilton-Toronto area in 1969. With the critical exception of the current extensive map cracking of steel slag HMA in Southern Ontario, considerable practical experience has shown the positive features of steel slag aggregates in dense-graded and open-graded HMA. These properties in HMA include high stability, good stripping resistance and excellent frictional properties (Emery, 1987b). However, in addition to the cracking, there have been problems with the consistency and overall quality of steel slag aggregate, that are largely a function of its batch production as a byproduct of the primary steel production. Steel companies, steel slag processors and

TABLE 14 STEEL SLAG USED (PRODUCED)* IN 1990 AND STOCKPILED

SUPPLIER	MNR		MTO		USED IN	STOCKPILED
	REGION	DISTRICT	REGION	DISTRICT	1990 TONNES	
A	S	Cambridge	C	Hamilton	350,000	0
B	C	Sault Ste. Marie	NW	Sault Ste. Marie	50,000 (150,000 to United States)	36,600 processed 5 million unprocessed
C	S	Maple	C	Toronto	45,400	0
D	S	Kemptville	E	Ottawa	38,100	0
E**	S	Aylmer	SW	Chatham	5,000	(could supply 50,000/year)
TOTAL					488,500	36,600 processed 5 million unprocessed

*Amount used equals that produced in 1990 except as noted.

**American company supplying into Ontario from Detroit; Ontario supply figures only given.

**TABLE 15 ONTARIO NICKEL AND COPPER SLAGS USED (PRODUCED)* IN
1990 AND STOCKPILED**

SUPPLIER	MNR		MTO		USED IN	STOCKPILED TONNES
	REGION	DISTRICT	REGION	DISTRICT	1990 TONNES	
A	C	Sudbury	N	Sudbury	1,000,000**a,b	400,000
B	C	Sudbury	N	Sudbury	(550,000c)	2,500,000
C	NE	Timmins	N	New Liskeard	stockpiled (150,000d) disposed	mine backfill and mill pond
TOTAL					1,000,000	2,900,000

*Amount used equals that produced in 1990 except as noted.

**Slag type and processing a. nickel slag (air-cooled);

b. copper slag (air-cooled);

c. nickel slag (granulated); and

d. copper slag (granulated).

**TABLE 16 ONTARIO FLY ASH AND BOTTOM ASH PRODUCTION AND USE
IN 1990 AND STOCKPILED**

GENERATING STATION	MNR		MTO		1990 PRODUCTION		1990 USE		STOCKPILED TONNES
	REGION	DISTRICT	REGION	DISTRICT	FLY ASH TONNES	BOTTOM ASH* TONNES	FLY ASH TONNES	BOTTOM ASH TONNES	
Lakeview	S	GTA	C	GTA	128,000	22,000	128,000	22,000	-
Nanticoke	S	Maple Aylmer	C	Toronto Hamilton	500,000 **	50,000	-	-	8 to 10 million (lagoons)
Lambton	S	Aylmer	SW	London	136,000	24,000	25,000	24,000	4 million(dry process)
Thunder Bay	NW	Thunder Bay	NW	Thunder Bay	100,000	15,000 *	34,000	15,000	500,000 (cemented)
Atikokan	NW	Fort Frances	NW	Thunder Bay	60,000	9,000 *	8,000	9,000	300,000 (dry process)
TOTALS					424,000 (dry process) 500,000 (wet process)	120,000	195,000	70,000***	0.5 million (cemented) 4.3 million (dry process) 8-10 million (in lagoons)

*Where specific production figures for bottom ash were not available, bottom ash production has been estimated as 15 percent of fly ash production.

**A wet ash handling system is currently employed, with fly ash and bottom ash sluiced into lagoons.

***Virtually all bottom ash that is available is fully utilized by Ontario Hydro.

steel slag aggregate suppliers must be careful to mitigate the potential impact of steel slag batch production and composition, and unique features such as potential expansion. JEGEL have developed strict special provisions for the use of steel slag aggregates that have been adopted by Metro Transportation (Metro, 1991b). The most important of these are: the steel slag must be washed; the processed, washed steel slag must be stored for a minimum of one month before use in HMA; and, most importantly, the steel slag must not contain any discernible soft lime particles or lime-oxide agglomerations. It is imperative that the map-cracking performance problems with steel slag aggregates in HMA in Southern Ontario be resolved, to ensure continued aggregate use.

3.5 NICKEL AND COPPER SLAGS

Nickel and copper slags are often considered together as metallurgical byproducts. They are both essentially iron-silicate nonferrous slags, very similar in chemical composition (Table 11) and potential applications (Emery, 1982; Emery, 1987b; Douglas, Malhotra and Emery, 1985). Nickel slag (air-cooled and granulated) is produced at Sudbury and copper slag at Sudbury (air-cooled and granulated) and Timmins (granulated), as indicated by the use, production and stockpile inventory data in Table 15. The air-cooled nickel and copper slags, which are typically coproduced and/or coprocessed, are fully used as quality rail ballast. This rail ballast use is typically one million tonnes per year. The Sudbury granulated nickel slag is stockpiled and the Timmins granulated copper slag is utilised in mine/mill operations. The challenge is clearly to find aggregate and/or cementitious uses for the granulated

nickel and copper slags. Extensive work on cementitious uses for nonferrous slags has been completed by CANMET (Douglas, Malhotra and Emery, 1985) and in Timmins by Kidd Creek Mines (Yu and Counter, 1983).

The use of Sudbury air-cooled nickel and copper slags in road and railway construction has been the subject of a fair amount of research (Emery, 1982). The iron-silicate slag is dumped and allowed to air cool so that a clinker is formed, and then crushed and processed as required. Nickel and copper slag from Sudbury has been used for fifty years as railway ballast. This has established itself as being the best material used. The processed slag is heavy, tough, hard, angular, and packs well under ties to form a better support for track than crushed rock ballast (Emery, 1982). It is likely that ballast, and some highway base, applications will continue to fully utilize Ontario air-cooled nickel and copper slags production.

There is a wide range of applications for granulated copper slag that should be considered, noting the considerable CANMET research that has already been completed for cementitious applications:

- cementitious - cemented mine backfill,
- applications - blended cement, base stabilization, waste treatment and sludge stabilization (these applications require grinding to a high fineness and activation with cement, for instance);
- and
- aggregate uses - winter sand, fine aggregate in HMA (stripping potential?), sand blushing

TABLE 17 ONTARIO CEMENT KILN DUST PRODUCTION IN 1990 AND STOCKPILED

SUPPLIER	MNR		MTO		1990 PRODUCTION TONNES	STOCKPILED TONNES
	REGION	DISTRICT	REGION	DISTRICT		
A	S	Tweed	E	Kingston	45,500	Landfilled on site
B	S	Maple	C	Port Hope	10,000	200,000
C	S	Cambridge	SW	Stratford	2,000	Landfilled on site*
D	S	GTA	C	GTA	25,000	>200,000
		Maple		Toronto		
E	S	Tweed	E	Kingston	50,000	>200,000
						(not cementitious)
F	S	Aylmer	SW	London	0	-
TOTAL					132,500	>600,000

*Produced as a wet slurry that is sluiced to a settling basin, allowed to set for easier handling with less dust, broken up with a bulldozer and then landfilled.

media, roofing granules, granular subbase and engineered fill.

There may be some interest at the MTO in considering the road-related aggregate uses.

3.6 FLY ASH AND BOTTOM ASH

Fly ash and bottom ash are coproduced wastes resulting from the combustion of pulverized coal in thermal power generation plants, as shown in Figure 5 (FHWA, 1986). Fly ash and bottom ash are produced at Ontario Hydro's five coal-fired thermal stations as listed in Table 16.

Information for this section was developed by JEGEL's retained consultant, concrete specialist Professor R. Douglas Hooton of the University of Toronto, based on experience with Ontario Hydro and discussions with Philip Buckingham, Program Manager of Fossil Byproducts at Ontario Hydro.

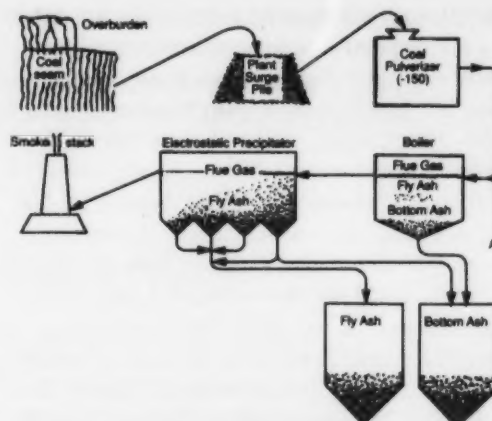


FIGURE 5 FLOW DIAGRAM OF COAL FUEL POWER PLANT SHOWING WASTE FLY ASH AND BOTTOM ASH (Adapted from Federal Highway Administration).

TABLE 18 ONTARIO LIME KILN DUST PRODUCTION IN 1990 AND STOCKPILED

SUPPLIER	MNR		MTO		1990 PRODUCTION TONNES	STOCKPILED TONNES
	REGION	DISTRICT	REGION	DISTRICT		
A	S	Cambridge	C	Hamilton	40,000	—
B	C	Sault Ste. Marie	NW	Sault Ste. Marie	8,000	70,000
C	C	Sault Ste. Marie	NW	Sault Ste. Marie.	13,000	(Mine disposal)
D	S	Aylmer	SW	London	11,000	Landfilled on site
TOTAL					72,000	70,000
						140,000

TABLE 19 ONTARIO WASTE FOUNDRY SAND 1989 PRODUCTION AND USE/DISPOSAL SITE

SUPPLIER	MNR		MTO		1989 PRODUCTION* TONNES	USE/DISPOSAL SITE*
	REGION	DISTRICT	REGION	DISTRICT		
A	S	Aylmer	SW	Chatham	5,000	Undisclosed
B	S	Cambridge	SW	Stratford	2,710	Asphalt Plant
C	S	Cambridge	C	Hamilton	7,260	Municipal Landfill
D	S	Cambridge	SW	Stratford	6,640	Private Landfill
E	S	Maple	C	Port Hope	2,590	Company Landfill
F	S	Aylmer	SW	Chatham	136,080	Municipal Landfill
G	S	Cambridge	C	Hamilton	101,200	Private Landfill
H	S	Cambridge	C	Hamilton	5,900	Private Landfill
TOTAL					267,380 **	

*Information provided by Manufacturing Research Corporation of Ontario (MRCO) from Confidential Report (D'Allesandro, L., Haas, R. and Cockfield, R.W., "Feasibility Study on the Environmentally and Economically Beneficial Use of Waste Foundry Sand in the Paving Industry") prepared for MRCO and the Canadian Foundry Group - Sand Exchange Project, University of Waterloo, November 1990.

**This 267,380 tonnes of waste foundry sand from the eight major sources represents about 75 percent of the total foundry sand used per year in Ontario (about 360,000 tonnes per year) (MNDM, 1988)

All stations except Nanticoke use a dry fly ash and bottom ash disposal process. Nanticoke, which currently uses a wet disposal process with storage lagoons, will be switching to a dry handling system in 1993/94. Nanticoke fly ash and bottom ash are not currently suitable for cementitious and aggregate applications due to their wet, mixed disposal method and resultant high moisture contents. The fly ash consistency at each station varies with the generation level, type of coal being burned and the dust control system employed. Low sulphur bituminous coal is used at Nanticoke, Lambton and Lakeview, and is blended with lignite coal from Saskatchewan at Thunder Bay and Atikokan. The lignite coal results in a higher fly ash carbon content that reduces the pozzolanic activity (cementitious potential) of this fly ash. The dust control system precipitators at Lambton, Nanticoke and two units at Lakeview employ an ammonia gas injection system to improve their efficiency. However, some residual ammonium sulphate remains in this fly ash that may cause problems with aggregate utilization. Scrubbers are to be installed on all of these units which will allow high sulphur coal to be used without the ammonia gas injection.

The present use of Ontario Hydro fly ash and bottom ash is indicated in Table 16. The fly ash is mostly Class F which is low in free CaO and therefore has limited cementitious properties, with some Class C produced at Thunder Bay and Atikokan that is self-cementing. All Lakeview fly ash is currently being used as cement kiln feed at four cement plants, with any bottom ash used as granular subbase for road construction. About 20 percent of Lambton's fly ash production is being used for the stabilization of hazardous liquid wastes by Laidlaw near Sarnia, with the remainder stockpiled. Some fly ash from Thunder Bay and Atikokan is being used as pozzolan in concrete and in cemented mine backfill.

Bottom ash, which is typically about 15 percent of total ash production, is generally used at the stations as granular subbase (Granular B) for site roads and storage pads. Some bottom ash becomes available for off-site use in road construction, but the quantities involved are usually small and variable. The Credit Valley Conservation Authority used about 5,000 tonnes of bottom ash from Lakeview in 1986 for parking area construction at the Lakefront Promenade Park in

Mississauga near the station. Material characteristics and environmental assessments of this specific bottom ash completed by JEGEL were favourable.

Processes have been developed for the use of fly ash in lightweight aggregate production. An unsuccessful pilot lightweight aggregate project was completed in the early 1970s at Lakeview that required pyro-processing of fly ash pellets. More economical processes have since been developed for fly ash such as Agglite lightweight aggregate production.

It appears that Ontario Hydro will continue to pursue full utilization of their fly ash and bottom ash, particularly when dry handling is introduced at Nanticoke. Apparently, the MOE has put controversial restrictions on the use of fly ash for engineered fill, by classifying it as a special waste which requires an environmental assessment for any land use of more than 50,000 tonnes. Engineered fill was a very successful use of fly ash in the 1980s as construction fill in highway overpasses, compacted fill for plants, etc. It is understood that the MOE is currently reviewing the status of such fly ash use in engineered fills with the current general focus on recycling and reuse. It would be worthwhile to develop fly ash engineered fill use guidelines meeting Ontario environmental requirements, particularly if Ontario Hydro cannot develop full fly ash use in cement kiln feed and cementitious applications.

3.7 CEMENT AND LIME KILN DUSTS

Most of the dust generated during the manufacture of portland cement and lime is produced during the calcining process in kilns. As the raw materials are heated and tumbled in the kiln, dust particles are created and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles are captured by efficient dust collection systems. The composition of cement and lime kiln dusts is quite variable from source to source due to raw materials and process variations. Cement kiln dust is made up of a variable amount of fine calcined and uncalcined feed materials (finely pulverized limestone and argillaceous materials), fine cement clinker, fuel combustion byproducts and condensed alkali compounds. Lime kiln dust is made up of variable amounts of fine lime, unburnt limestone and combustion byproducts (Collins and Emery, 1983).

TABLE 20 ONTARIO PRODUCTION OF MINE WASTES - WASTE ROCK AND TAILINGS

TABLE 20A ONTARIO MINE WASTES 1990 PRODUCTION AND STOCKPILED BY MNR REGION

MNR REGION/DISTRICT	NO. OF MINES	WASTE ROCK*		TAILINGS*	
		1990 PRODUCTION TONNES	CURRENTLY STOCKPILED TONNES	1990 PRODUCTION TONNES	CURRENTLY STOCKPILED TONNES
Southern**					
Maple	0	-	-	-	-
Aylmer	0	-	-	-	-
Cambridge	4	160,000	3,000	0	0
Kemptville	0	-	-	-	-
Midhurst	0	-	-	-	-
Tweed	1	180,000	40,000	120,000	>1 million
	5	340,000	43,000	120,000	>1 million
Central					
Sault Ste. Marie	5	-	-	-	-
Sudbury	17+1 closed	60,000	40 million	15.2 million	>50 million
North Bay	7 closed	all closed	72 million	all closed	>56 million
Parry Sound	0	-	-	-	-
Bancroft	0	-	-	-	-
Pembroke	0	-	-	-	-
	22+8 closed	60,000	112 million	15.2 million	>106 million
Northeast					
Hearst	0	-	-	-	-
Wawa	6	>286,000	250,000	>630,000	>88 million
Chapleau	1	-	27,500	-	400,000
Timmins	13+3 closed	1.6 million	12.8 million	2.4 million	>146 million
Cochrane	0	-	-	-	-
Kirkland Lake	3+1 closed	375	70 million	1.1 million	>163 million
	23+4 closed	≈1.9 million	83 million	>4.1 million	>318.2 million
Northwest					
Kenora	0	-	-	-	-
Dryden	2	12,500	25,000	-	-
Fort Frances	0	-	-	-	-
Red Lake	3	163,000	500,000	>160,000	10 million
Sioux Lookout	0	-	-	-	-
Thunder Bay	0	-	-	-	-
Nipigon	1	40,000	250,000	-	-
Geraldton	1 closed	-	-	-	200,000
	6+1 closed	215,500	775,000	>160,000	10.2 million
TOTALS	56+13 closed	≈2.5 million	>196 million	>19.6 million	>435 million

*Large quantities available but not much suitable for aggregate applications due to poor physical characteristics and chemical activity (acid generation).

TABLE 20B ONTARIO MINE WASTES 1990 PRODUCTION AND STOCKPILED BY MTO REGION

MTO REGION/DISTRICT	NO. OF MINES	WASTE ROCK*		TAILINGS*	
		1990 PRODUCTION TONNES	CURRENTLY STOCKPILED TONNES	1990 PRODUCTION TONNES	CURRENTLY STOCKPILED TONNES
Central	-	-	-	-	-
Southwestern	4	160,000	3,000	-	-
Eastern	1	180,000	40,000	120,000	>1 million
Northern					
Huntsville	0	-	-	-	-
Sudbury	22+1 closed	>>60,000	40.3 million	15.2 million	>>50 million
North Bay	5 closed	-	<1,000	-	-
New Liskeard	17+5 closed	1.6 million	155 million	3.6 million	>365 million
Cochrane	-	-	-	-	-
	39+11 closed	>1.66 million	195 million	18.8 million	>415 million
Northwestern					
Sault Ste. Marie	8	317,000	285,500	>630,000	>9.2 million
Thunder Bay	2+1 closed	52,500	275,000	-	>>200,000
Kenora	2+1 closed	163,000	>500,000	160,000	>10 million
	12+2 closed	532,500	>1,060,500	>790,000	>19.4 million
TOTALS	56+13 closed	≈2.5 million	196 million	>19.6 million	>435 million

*Large quantities available but not much suitable for aggregate applications due to poor physical characteristics and chemical activity (acid generation).

The Ontario 1990 cement and lime kiln dust production and stockpile inventory data are given in Tables 17 and 18 respectively. While 1990 external cement and lime kiln dust use was indicated by industry contacts to be minimal, significant amounts have been and are used for wet soil stabilization, sludge stabilization, waste stabilization and waste solidification (Emery, 1981). For instance, JEGEL is currently involved with the solidification of 100,000 tonnes of wet fly ash using about 10 percent lime kiln dust addition.

The increased use of cement and lime kiln dusts to replace lime in stabilization processes will make a modest contribution to cementitious (energy-intensive manufacture) materials conservation. There is also the potential for the use of cement and lime kiln dusts as fillers, for instance in HMA (Kraszowski and Emery, 1981).

3.8 WASTE FOUNDRY SAND

The Ontario foundry industry, consisting of about 75 ferrous (iron and steel) and 60 nonferrous foundries, produces annually some 250,000 to 350,000 tonnes of waste foundry sand (foundry sand) (MNDM, 1988, and information provided by Manufacturing Research Corporation of Ontario, MRCO, Table 19). Information

on 1990 waste foundry sand production and disposal for the eight largest ferrous foundries (about 75 percent of casting production) provided by MRCO is summarized in Table 19. Extrapolation of this waste foundry sand production to the overall ferrous foundry industry sand use indicates some 360,000 tonnes may be available, but the 267,000 tonnes of waste foundry sand produced by the large producers has been considered more representative for applications such as fine aggregate in HMA.

Foundry sand consists of high quality silica sand, imported into Ontario, that is bonded to form the mould for iron and steel castings. The most common bonding material is bentonite ('greensand' - 85 percent silica sand, 10 percent bentonite and 5 percent coal), with chemical bonding systems (3 percent organic binder such as phenolic urethane) also used. The availability of waste foundry sand tends to be centred in Hamilton, Windsor, St. Catharines and Cambridge. The disposal of waste foundry sand is becoming increasingly more costly (in 1991 \$72 per tonne in the Cambridge area for instance), so that uses for foundry sand are being investigated.

A study by the University of Waterloo for the Canadian Foundry Group (MRCO) considered uses such as brick

or mortar sand, concrete sand, asphalt sand, cement kiln feed, fill applications and foundry industry reuse. This research has recently been extended by MOE to a current JEGEL study considering a wide range of potential waste foundry sand uses in addition to fine aggregate in HMA. While waste foundry sand is generally considered to be nonhazardous, constituents such as heavy metals and phenols in some waste foundry sand may preclude many fill applications, and waste foundry sand appears to have a high corrosion potential. With the increasing cost of landfilling, and limited uses for waste foundry sand, the regeneration of waste foundry sand for reuse in the foundry may become more attractive as the technology is further developed.

At present, the most practical use of waste foundry sand appears to be as fine aggregate in HMA, provided care is taken that the foundry sand is clean and there is not a stripping potential. Waste foundry sand from three locations in the St. Catharines area are given in the MTO Aggregate Sources List for HMA fine aggregate. JEGEL experience indicates that up to about 15 percent clean waste foundry sand can be incorporated in HMA, subject to complete Marshall mix design and Immersion Marshall testing.

The findings of the current JEGEL waste foundry sand utilization study for the MOE will be of importance to the technically-sound use of waste foundry sand in aggregate applications. This study will also consider the environmental and economic factors involved with waste foundry sand recycling and reuse.

3.9 MINE WASTES

Mining and mineral processing operations are generally the largest source of solid wastes, and Ontario is no exception in this regard (Miller and Collins, 1976; OECD, 1977; Collings, 1984). Mining wastes are made up of broken rock from open pits and underground mines (mine waste rock), coarse mill rejects from screening and separation processes, and mill tailings. Most of these mine wastes have limited potential for reuse as aggregates due to their fineness, chemical activity (acid generation (Scales, 1991)), high impurity content, variability, radioactivity and/or remote location. However, some mine waste rock may be of interest because of suitable physical and chemical characteristics, and favourable location (transportation costs), for use as granular, ballast, concrete aggregate,

asphalt aggregate, engineered fill, etc. For instance, byproduct coarse and fine trap rock from a roofing granule manufacturer in Havelock is considered to be an aggregate and is used in HMA* surface course mixes as a premium quality aggregate (OPSS).

The Ontario mining and mineral processing industry was surveyed to produce the inventory of 1990 mine waste (waste rock and tailings) production and stockpiles given in Tables 20A and 20B respectively. It is clear that the current production (about 2.5 million tonnes) and stockpiles (greater than 106 million tonnes) of mine waste rock are large, but use will be severely limited by poor physical characteristics, chemical activity (acid generation) and transportation costs to Southern aggregate demand points.

It would appear, with the exception of trap rock, that not much use is being made of mine waste rock in Southern Ontario. Any major use is usually associated with mine development and road work. Algoma Steel uses iron silicate waste rock (20,000 to 50,000 tonnes per annum) as railroad ballast. Giant Yellowknife Mines have sold about 110,000 tonnes of heap leach waste rock (OPSS Granular A and M gradations) over the past four years for use in local roads.

It is unlikely that significant use of mine waste rock will be made in Ontario until favourable transportation costs to Southern Ontario are available. Garbage train backhauls have been advocated, but it now appears that the MOE will not permit GTA garbage to be hauled into Northern Ontario. There is probably little potential for the use of mine tailings.

3.10 MISCELLANEOUS WASTES

Several relatively small quantity wastes including demolition wastes, waste shingles, waste tires and waste glass were also considered as they have specific applications in construction and are receiving considerable public attention.

3.10.1 Demolition Wastes

Demolition and construction wastes include old concrete (foundations, slabs, columns, floors, etc.), bricks and masonry, wood and a number of materials such as dry wall, glass, insulation, roofing, wire, pipe, rock and soil. This demolition and construction waste can make up a significant component of the municipal solid waste stream that must be diverted from landfills

*See Appendix B for aggregate types used in HMA.

whenever possible (Metro, 1991a; Apotheker, 1990; Preistner, 1990). The Toronto Home Builders Association found in a recent study (THBA, 1990) that about three tonnes of waste material is generated for each new home constructed in the GTA, of which some 60 percent, or about 54,000 tonnes in 1990, goes into landfills.

A comprehensive study of the recycling potential of construction and demolition wastes for the State of Vermont indicated similar findings as experienced in the GTA (Spencer, 1991). For Vermont, two thirds of this waste was generated from transportation related construction activities and one third from buildings. Old asphalt was the largest amount of waste generated (46 percent) and recycled (50 percent).

The Toronto Construction Association, through the Council of Ontario Construction Associations, is currently completing a study to characterize and quantify demolition wastes for various building types at ten sites. This follows work completed by the Daniels Corporation and Greenspoon Brothers Limited during the demolition of the former Goodyear Tire factory for the Lakeshore Village Development in Etobicoke. At this site, concrete footings and floor slabs (about 35,000 tonnes) were crushed to produce specification Granular A base and pipe bedding for site use. Clean brick materials were crushed into screenings (minus 4.75 mm sieve size) for site landscaping (landscapers do not want mortar in crushed brick) and wood wastes (flooring) were chipped for horticultural dressing (only unimpregnated, unpainted wood is acceptable for this purpose). By recycling these materials with a portable processing plant on site, about 3,000 truck loads of demolition wastes were diverted from landfill. A similar old concrete recycling plant was also used at the Skydome site, and is still processing old concrete (RCM) from the railway lands development for use as granular material.

Old asphalt (RAP) and old concrete (RCM) from demolition projects can also be recycled at a number of hot-mix plant sites in Southern Ontario (particularly in the GTA) as indicated previously. There are also companies becoming established for aggregate recycling on a centralized basis such as Finbow Aggregate Recycling in Niagara Falls. With the increasing cost of landfilling waste materials, and the banning of recyclable materials from landfill, for example by Metro Toronto (Metro, 1991a), the on-site

and central plant recycling of RAP, RCM, brick, drywall and wood waste can only increase.

3.10.2 Waste Shingles

There is a significant volume of waste shingles that can be recycled in HMA to recover the cellulosic, filler, aggregate and asphalt cement content (Paulsen, Stroup-Gardiner and Epps, 1987). This is recovered from about 100,000 roofs per year each with two tonnes of waste shingles, for a total of some 200,000 tonnes, with additional scrap available from shingle production, going into Ontario landfill sites. Such recycling is now done regularly in the United States and the necessary recycling equipment for hot-mix plants has been developed (Apotheker, 1990). Small trials have been completed in Southern Ontario and this use of waste shingles will probably develop as a cost saving, material conservation alternative to landfilling. This technology might also be applicable to the wastes from the replacement of asphalt cement based roofing.

3.10.3 Waste Tires

In the past two years, the recycling of waste tires in road construction has received extensive MOE and media attention, particularly in contrast to higher volume wastes such as shingles and demolition materials. About 12 million scrap passenger tire equivalents are generated in Ontario each year (about 50 percent in the GTA), or about 100,000 tonnes. MTO trials of both asphalt rubber (rubber as part of binder) and rubber-modified asphalt concrete (RUMAC, rubber essentially as aggregate) are in progress, and both technologies are used commercially in the United States (Lynch and Northwood, 1991; Kearney, 1990). The most extensive use of waste tires as asphalt rubber appears to be by the City of Phoenix for over twenty years, with good performance indicated and significant technical guidance published (Charania, Caro and Schnormeir, 1991).

The main contribution to aggregate conservation through the use of waste tires in roads will be in extending the pavement service life. This life is reported by some to be about doubled (Kearney, 1990). While both rubber asphalt and RUMAC have high initial costs, there is no agreement on the service life improvements, and no recognized Ontario technical standards for rubber asphalt and RUMAC (Kearney, 1990; Anon, 1991). There also appears to be hot-mix industry resistance to the use of waste tires in roads

**TABLE 21 STATE LEGISLATION (1990)
WASTE AND BYPRODUCTS USE IN CONSTRUCTION APPLICATIONS***

STATE	USE ENCOURAGED
California	Old Asphalt, Old Concrete, Waste Foundry Sand, Waste Tires, Waste Glass
Colorado	Waste Tires
Connecticut	Old Asphalt, Old Concrete, Waste Glass, Demolition Waste
Florida	Fly Ash, Waste Tires, Waste Glass, Waste Plastic
Georgia	Old Asphalt, Fly Ash, Bottom Ash, Silica Fume, Waste Tires**
Missouri	Waste Tires
BID PREFERENCE OR USE MANDATORY	
Pennsylvania	All Recyclable Materials (Bid Preference Legislated)
Texas	Waste Tires (Bid Preference Legislated)
Wisconsin***	Old Asphalt (Pavement), Fly Ash, Foundry Sand, Waste Tires, Waste Glass

* From survey of State and District of Columbia Transportation Departments (100 percent response). No comparable Provincial or Territorial legislation was identified during the survey.

**Use mandatory in rubberized crack sealant.

***Use mandatory.

(Sidlar, 1991). Regardless, the recycling of waste tires in HMA has clearly become an MOE focus, while others advocate a wider range utilization strategy including use as fuel in cement kilns (Kearney, 1990).

3.10.4 Waste Glass

The appropriate approach for handling collected glass is to recycle it back into the glass market. However, some collected glass is contaminated (for example with ceramics) or otherwise not suitable for recycling for various reasons. Such waste glass can be used as aggregate in Glasphalt, which was developed in the 1970s (Gunner, 1990). For Glasphalt, waste glass is typically incorporated to replace 20 percent of the aggregate in binder course HMA, with one percent hydrated lime adhesion/antistripping added. Such use of waste glass in HMA is now covered by the Metro Transportation MT 701 Specification (Metro, 1991b).

With the blue box recycling program in Ontario, the amount of available scrap glass will probably remain small; other uses such as mixing in granular subbase are far simpler and contribute equally to aggregate conservation. However, such mixing in granular material is apparently not permitted by the MOE as the construction site may become classified as a waste disposal site.

3.10.5 General

Within the context of Ontario aggregates annual production approaching 200 million tonnes, the use of low volume wastes such as waste tires and waste glass will contribute very little to aggregates conservation. There is also a wide range of miscellaneous, generally low volume, wastes identified in Table 5 that have found some use in construction. However because of their low volumes, these wastes will make little contribution to aggregate conservation. The seven wastes and byproducts of greatest interest to aggregate conservation in Ontario are clearly old asphalt, old concrete, blast furnace slag, steel slag, nickel and copper slags, fly ash and bottom ash.

4. FACTORS INHIBITING AND SUPPORTING REUSE AND RECYCLING

4.1 INHIBITING FACTORS

Throughout the study, it was possible to assess various identified technical, economic and environmental factors that tend to discourage (inhibit) and encourage (support) the reuse and recycling of wastes and byproducts for aggregates conservation (bulk and cementitious applications). The generic inhibiting

factors for wastes and byproducts utilization in construction, as given in the introduction, include (Emery, 1978; MNDM, 1990; ENDS, 1991):

1. agency resistance to adopting new materials and construction technology (conservatism);
2. obsolete specifications;
3. inadequate research and development budgets;
4. liability concerns for innovative technologies;
5. environmental constraints on recyclable wastes that are not applied to conventional materials;
6. industry processing and pricing based on new materials;
7. widely scattered distribution or small quantities of wastes;
8. collection, storage and processing costs;
9. lack of technical guidance; and
10. the inherent variability of many wastes and byproducts.

From this listing, several specific, inhibiting factors for wastes and byproducts utilization in construction were identified during technical discussions with agency, industry/ contractor and consultant staff, and during inventory activities. These factors have generally been outlined in previous sections for the wastes and byproducts of greatest interest as follows, with the suggested agency or industry to take note.

1. Some agencies are not using suitable wastes and byproducts in their construction projects even with MTO leadership and demonstrated satisfactory performance. This is due to a lack of Ontario Provincial Standard Specifications (OPSS) coverage. Despite the wider use of reclaimed asphalt pavement (RAP) and reclaimed concrete material (RCM) as in the GTA, there are still large stockpiles of RAP and RCM available. This could be resolved through the Ontario Provincial Standards Pavement Committee focusing on the relevant MTO special provisions and developing corresponding OPS specifications for regular agency use. Unfortunately this can be a time-consuming process as is the case for a recycled hot mix (RHM) OPSS currently under agency and industry review. The MTO may consider producing a pavement recycling manual, giving standard specification sections for agency use in contract documents;

2. There is apparently some agency and industry concern with regard to MOE and MTO, requirements for wastes and byproducts use in construction in terms of the Ontario Environmental Protection Act and Regulation 309. Most of the environmental concerns would be alleviated by the use of the MOE Waste Management Branch guide called "Management of Surplus/ Waste Materials Generated through Road Maintenance and Construction" (MOE, 1988). This guide is apparently under joint MOE/MTO review. From this guide, the wastes and byproducts of greatest interest (Tables 5 and 7) are generally not considered to be wastes as they are being put to a constructive use, or are considered to be inert fill. All materials are to be handled in an environmentally responsive manner. A more detailed MOE/MTO guide, giving specific environmental information for each major waste and byproduct used in construction, would be helpful to the construction industry and may foster more reuse and recycling; and
3. There is some limitation on the developed range of applications for specific wastes and byproducts in construction (RAP in heavy duty/high stability binder course hot-mix asphalt (HMA) for instance) that may prevent full reuse and recycling of a material. This is largely a function of agency research and development budget constraints. It would appear that only MTO has the necessary technical resources to undertake such work and to generally establish new specifications.

It should be noted that no totally limiting constraint(s) on the use of wastes and byproducts of interest was identified during the study. Ontario appears to be providing a progressive environment for aggregates conservation throughout the construction industry (agencies, suppliers, contractors and consultants). This is particularly true when overall economics are favourable.

4.2 SUPPORTING FACTORS

It was found during the survey of transportation departments (Table 5) that there is no Province currently legislating the use of wastes and byproducts in construction. Several U.S. states have legislation or pending legislation, encouraging the use, or

consideration, of specific wastes and byproducts in construction (RAP, RCM, fly ash, waste tires, waste glass, etc.) as summarized in Table 21. However, a review of the actual documents indicated a limited scope and applicability with only a few mandatory uses identified. The only significant general waste utilization legislation identified for Canada and the United States is the U.S. Resource Conservation and Recovery Act (RCRA, Section 6002). It requires federal, state and local procuring agencies using appropriated federal funds "to purchase items composed of the highest percentage of recovered materials practicable". The EPA, in implementing the RCRA, has developed relevant procurement guidelines for cement and concrete containing fly ash, asphalt materials containing ground scrap tire rubber used for construction and rehabilitation of pavement surfaces (not implemented), and building insulation containing recovered materials. These EPA procurement guidelines provide significant technical information and supporting data, but appear to be very complicated (MacDonald, 1991).

For Ontario, it appears that there are two factors of government policy that encourage the reuse and recycling of wastes and byproducts:

1. Emphasis on resource conservation and sustainable development through the 3Rs of reduction, reuse and recycling. This may not directly enhance the economic viability of waste and byproduct reuse and recycling as aggregates, but certainly provides a strong motivating framework, particularly when coupled with concerns for aggregate extraction and economic availability near urban demand points (NEC, 1991); and
2. Restrictions on landfilling of recyclable materials (Metro Toronto bans old concrete, old asphalt and construction rubble) and the escalating cost of landfilling in many areas such as the GTA (Metro, 1991a). The constraints and cost of landfilling potentially recyclable materials is considered to be the current major driving force for the increased reuse and recycling of wastes and byproducts in Ontario.

It must also be recognized that some byproducts (blast furnace slags and traprock for instance) have always been considered as aggregates and some recycling (RAP and RCM) uses were well developed long before sustainable society concerns emerged (Wilkinson, 1991).

5. CONCLUSIONS

There are seven wastes and byproducts - old asphalt, old concrete, blast furnace slag, steel slag, nickel and copper slags, fly ash and bottom ash - that make a significant contribution to aggregates conservation in Ontario. Additionally, cement and lime kiln dusts, waste foundry sand, mine waste rock and several miscellaneous materials (demolition wastes, waste shingles, waste tires, waste glass, etc.) could contribute in the future, particularly technically suitable mine waste rock with favourable transportation costs from the north to southern aggregate demand centres. On the other hand, performance problems with steel slag aggregates in hot-mix asphalt will undoubtedly significantly decrease the use of this important aggregate source unless resolved. About 66 percent of the available annual production of wastes and byproducts (excluding mine waste rock) is utilized.

On balance, based on the 1990 use data for the wastes and byproducts of interest for reuse and recycling as aggregates (bulk and cementitious applications), the contribution to aggregates conservation can be summarized for Ontario and the GTA as follows:

	1990		1995 Pessimistic		1995 Optimistic	
	Ontario	GTA	Ontario	GTA	Ontario	GTA
Wastes and Byproducts Used (million tonnes)	5.9	1.7	6.0	2.3	9.0	3.7
Percent of Aggregates Production	3.3	2.4	3.3	2.8	5.0	4.5

The Ontario aggregates production has been estimated as 180 million tonnes for 1990 (held constant to 1995) and the GTA aggregates consumption has been estimated as 72 million tonnes for 1990 (40 percent of Ontario total, held constant to 1995). The 1995 pessimistic projection is essentially based on the loss of steel slag as an aggregate, a 50 percent increase in the use of RAP and RCM in the GTA, and no other significant increase in wastes and byproducts reuse and recycling. The 1995 optimistic projection is based on full use of steel slag as an aggregate, a 100 percent increase in the use of RAP and RCM in the GTA, a 50 percent increase in the use of RAP and RCM outside of the GTA, use of 1 million tonnes of mine waste rock (50 percent in the GTA), and no other significant increase in wastes and byproducts reuse and recycling. A ten percent increase in overall waste and byproducts use

total has been applied to approximate miscellaneous uses and small quantities.

From the above, the current (1990) use of waste and byproducts for aggregates is some 6 million tonnes (about 3 percent of Ontario aggregates production) and the 1995 estimated use ranges from 6 to 9 million tonnes (3 to 5 percent of Ontario aggregates production). Although the contribution of wastes and byproducts reuse and recycling as aggregate has a small impact on Ontario's total aggregate production, it is still significant in terms of resource conservation and in alleviating landfill concerns.

6. RECOMMENDATIONS

Several areas of action and development have been identified to enhance the general use of wastes and byproducts, and specific uses for wastes such as old concrete and old asphalt. General areas of improvement include: developing OPSS coverage of standard waste and byproducts use in road construction; developing an environmental guide for the use of wastes and byproducts in construction; and developing more uses for wastes such as old asphalt and old concrete. It is critical that the cause and solution of map cracking of asphalt pavements incorporating steel slag aggregates be resolved in order to preserve this important aggregate source. Other areas of enhanced specific waste and byproduct use include: use of RAP in heavy duty/high stability binder course recycled hot mix; use of fine manufactured sand in recycled hot mix for air voids development; and establishing environmental guidelines for the use of fly ash in engineered fill. These recommendations are given in detail throughout the study.

It is projected that wastes and byproducts reuse and recycling will continue to make only a modest contribution to aggregates conservation (some 3 to 5 percent of total aggregates consumption). However, the most significant contribution will continue to be in overall materials, energy and landfill space conservation. The prime supporting factors for aggregate conservation through reuse and recycling will probably be through government practices of sustainable development and ever increasing landfill constraints.

REFERENCES

Anon

1991: Rubber Roads Debated; ENR, Vol. 227, No. 5, p.10.

APAO

1988: Did You Know?; Aggregate Producers' Association of Ontario, Aggregate Industry Fact Sheet, 4p.

Apotheker, S.

1990: Construction and Demolition Debris - The Invisible Waste Stream; Resource Recycling, December, p.66-68, 70, 72-74.

Bancsi, J.J., Benedek, A., Emery, J.J. and Lawrence, J.

1980: The Leaching of Toxic Organic Compounds from Solid Wastes; unpublished paper presented at U.S. EPA National Conference on Management of Uncontrolled Hazardous Waste Sites, Washington, October, copy on file, 22p.

Bradbury, A., Kazmierowski, T.J., Cheng, S. and Raymond, C.

1991: Evaluation of a Cold In-Place Recycling Project in Ontario; paper in press presented at Transportation Association of Canada Annual Conference, Winnipeg, September, copy on file, 21p.

Charania, E., Cano, J.O. and Schnormeir, R.H.

1991: A Twenty Year Study of Asphalt-Rubber Pavements in the City of Phoenix, Arizona; Asphalt Rubber Producers Group, Phoenix, 15p.

Clifton, J.R., Brown, P.W. and Frohnsdorff, G.

1977: Survey of Uses of Waste Materials in Construction in the United States; National Bureau of Standards, U.S. Department of Commerce, Report NBSIR 77-1244, 62p.

Collings, R.K.

1984: Current and Potential Uses for Mining and Mineral Processing Wastes in Canada: Standards; Journal of Testing and Evaluation, Vol. 12, No. 1, p.46-50.

Collins, R.J. and Emery, J.J.

1983: Kiln Dust-Fly Ash Systems for Highway Bases and Subbases; Federal Highway Administration, U.S. Department of Transportation, Report FHWA/RD-82/167, 135p.

Dialog

1991: Pocket Guide to DIALOG⁺; Dialog Information Services, Inc., Palo Alto, 43p. Douglas, E., Malhotra, V.M. and Emery, J.J.

1985: Cementitious Properties of Nonferrous Slags from Canadian Sources; Cement, Concrete and Aggregates, Vol. 7, No. 1, p.3-14.

Earl, J.F. and Emery, J.J.

1987: Practical Experience with High Ratio Hot Mix Recycling; Canadian Technical Asphalt Association, 32nd Annual Meeting, Toronto, November, Proceedings, p.326-339.

Emery, J.J.

1978: Utilization of Wastes and Byproducts as Construction Materials in Canada; Conservation and Recycling, Vol. 2, No. 1, p.31-41.

1981: Stabilizing Industrial Sludge for Fill Applications; Seventh International Congress on the Chemistry of Cement, Paris, July 1980, Proceedings, Vol. 4, p.644-648.

1982: Slag Utilization in Pavement Construction; in Extending Aggregate Resources, American Society for Testing and Materials, STP 774, p.95-118.

1984: Residuals and Byproducts as Construction Materials; 6th Industrial Minerals International Congress, Toronto, May, Proceedings, p.JJE1-JJE15.

- 1987a: Japanese and Canadian Use of Steel Slag Aggregate in Asphalt Mixes; unpublished paper presented at Paving in Cold Areas Workshop 3 (PICA-3), Ottawa, July, copy on file, 26p.
- 1987b: Review of North American Slag Production and Utilization; unpublished paper presented at CANMET, Energy, Mines and Resources Canada Workshop, Ground Granulated Blast Furnace Slag in Concrete, Mississauga, September, copy on file, 16p.
- Emery, J.J. and Terao, M.
1990: Asphalt Technology for Hot In-place Recycling; Paving in Cold Areas Workshop 4 (PICA-4), Sapporo, Proceedings, Vol. 2, p.75-104.
- EMR
1990: 1989 Canadian Minerals Yearbook - Review and Outlook; Energy, Mines and Resources Canada, Mineral Report No. 38, 1.1-70.109p.
- ENDS
1991: Institutional Barriers Block the Path to Road Recycling; ENDS Report 194, March, p.19-21.
- Ferguson, R.G.
1989: The Current Situation in Metropolitan Toronto and the Greater Toronto Area; Environment Canada 11th Canadian Waste Management Conference, Montreal, September, Proceedings, p.199-218.
- FHWA
1986: Fly Ash Facts for Highway Engineers; Federal Highway Administration, U.S. Department of Transportation, Demonstration Projects Program, July, 47p.
- 1987: Pavement Recycling Guidelines for Local Governments - Executive Summary; Federal Highway Administration, U.S. Department of Transportation, Report FHWA-TS-87-230, September, 33p.
- Gunner, N.
1990: Glasphalt Turns Waste Into Paving Material; Construction Record, August-September, p.22,25,26.
- Gutt, W. and Nixon, F.J.
1978: Use of Waste Materials in the Construction Industry - Analysis of the RILEM Symposium by Correspondence; Matériaux et Constructions, Vol. 12, No. 70, p.255-306.
- Hanks, A.J. and Magni, E.R.
1989: The Use of Recovered Bituminous and Concrete Materials in Granular and Earth; Engineering Materials Office, Ontario Ministry of Transportation, Report MI-137, December, 87p.
- Hooton, R.D. and Emery, J.J.
1990: Sulfate Resistance of a Canadian Slag Cement; ACI Materials Journal, Vol. 87, No. 6, p.547-555.
- IGGA
1990: Grinding Slurry Analysis; International Grooving and Grinding Association, Skyland, November, 4p.
- Katona, Z.
1991: Bituminous Materials: A Future Challenge, Recycling Asphalt and Concrete; Ontario Good Roads Association, Milestone '91, June, p.52,55,56.
- Kearney, A.T.
1990: Scrap Tire Use/Disposal Study; Scrap Tire Management Council, Washington, Final Report, 66p.
- Kraszowski, L. and Emery, J.J.
1981: Use of Cement Kiln Dust as a Filler in Asphalt Mixes; Ontario Research Foundation/CANMET Symposium on Mineral Fillers, Toronto, October, Proceedings, 23p.

Kriech, A.J.

1991: Evaluation of RAP in Clean Fill; Asphalt, Vol. 5, No. 1, p.8-9.

Lynch, D.F. and Northwood, R.P.

1991: The Waste Tire Paving Demonstration Project at Thamesville, Ontario; paper in press presented at Transportation Association of Canada Annual Conference, Winnipeg, September, copy on file, 17p.

MacDonald, A.

1991: How Effective are Federal Procurement Policies?; BioCycles, Vol. 32, No. 9, p.47-49.

Miller, R.H. and Collins, R.J.

1991: Waste Materials as Potential Replacements for Highway Aggregates; Transportation Research Board, NCHRP Report 166, Washington, 94p.

Metro

1991a: We Can't Take it Any More; Municipality of Metropolitan Toronto, Works Department, Newspaper Advertisement, Spring, copy on file, 1p.

1991b: Specification for Hot Mix, Hot Laid Asphaltic Concrete; Municipality of Metropolitan Toronto, Transportation Department, MT 701, Revision 1, Metric, January, 41p.

Miller, R.H. and Collins, R.J.

1976: Waste Materials as Potential Replacements for Highway Aggregates; Transportation Research Board, NCHRP Report 166, Washington, 94p.

MNDM

1988: The Foundry Industry in Ontario and Outlook for Industrial Minerals; report prepared by Gallagher and Associates for Ontario Ministry of Northern Development and Mines, Industrial Mineral Background Paper 7, 44p.

1990: Developments in Building Products: Opportunities for Industrial Minerals; report prepared by IRC and Malex Consultants Inc., for Ontario Ministry of Northern Development and Mines, Industrial Mineral Background Paper 13, 163p.

MNR

1990: 1989 MNR Aggregate Resources Program Statistical Update; Aggregate Resources Section, Ontario Ministry of Natural Resources, March, unpublished data, copy on file, 2p.

MOE

1988: Management of Surplus/Waste Materials Generated through Road Maintenance and Construction; Waste Management Branch, Ontario Ministry of the Environment, September, 6p.

1990: Towards a Sustainable Waste Management System; Ontario Ministry of the Environment, Discussion Paper, 43p.

NEC

1991: Proposed Revisions to the Niagara Escarpment Plan; Niagara Escarpment Commission, Niagara Escarpment Plan Review, January, 81p.

NSA

1988: Another Slag Success Story; National Slag Association, Alexandria, MF 188-3, 2p.

OECD.

1977: Use of Waste Materials and Byproducts in Road Construction; Organization for Economic Cooperation and Development, Paris, 168p.

OHMPA

1990: Paving the Way, 1990 OHMPA Asphalt Seminar, Ontario Hot Mix Producers Association, Brochure, 2p.

Owens, J.F.

1988: Slag-Iron and Steel; Bureau of Mines, U.S. Department of the Interior, section, Minerals Yearbook - 1988, 13p.

Parker, S.

1991: Asphalt: Good Citizen in Landfills; Asphalt Contractor, July-August, p.12,82.

Paulsen, G., Stroup-Gardiner, M. and Epps, J.

1987: Recycling Waste Roofing Material in Asphalt Paving Mixtures; Transportation Research Board, Transportation Research Board Record 1115, p.171-182.

Preistner, W.J.

1990: Construction and Demolition Wastes: Problem or Product; Hazardous Materials Management, Vol. 2, No. 6, p.34-36.

Puckman, K., Heinrichsen A. and Hansen, D.R.

1988: Reuse of Concrete Pavements; National Road Laboratory, Danish Ministry of Transportation, Report 63E, 36p.

Scales, M.

1991: Special Report: Acid Drainage; Canadian Mining Journal, 1991 Mining Sourcebook, 100th Edition, p.11-13,15.

Sidlar, G.

1991: Rubber Tire Solution Needs Thorough Research; Ontario Hot Mix Producers Association, Asphalttopics, July, 1p.

Spencer, R.

1991: Taking Control of C + O Debris; BioCycle, Vol. 32, No. 7, p.65-68.

THBA,

1990: Making a Molehill out of a Mountain; prepared by REIC Consulting Ltd., Renova Consultants and RIS Ltd., for Toronto Home Builders Association, 29p.

Thompson, E. and Haas, R.

1991: Health and Environmental Effects of Fumes from Asphalt Paving; paper in press presented at Transportation Association of Canada Annual Conference, Winnipeg, September, copy on file, 20p.

Wilkinson, S.

1991: The Greening of Ontario; Ontario Ministry of Transportation, Inside Routes, Vol. 2, No. 3, p.1,3.

Yu, T.R. and Counter, D.B.

1983: Backfill Practice and Technology at Kidd Creek Mines; CIM Bulletin, Vol. 76, No. 856, p.56-65.

APPENDICES

APPENDIX A

DEFINITIONS

These definitions are for the non-specialist and should not be considered technically complete. An extensive compilation of standard technical definitions is available from ASTM (ASTM, Compilation of ASTM Standard Definitions, 7th Edition, American Society for Testing and Materials, Philadelphia, 1990).

OPSS - Ontario Provincial Standard Specification

CSA - Canadian Standards Association

absorption:	fluid entering permeable pores of a solid material, given as percent increase in mass.
aggregate:	granular material of mineral composition, such as sand, gravel, crushed stone or processed blast furnace slag, used in building and road construction (OPSS 1001, 1002, 1003, 1004 AND 1010 and CSA Standard A23.1).
antistripping additive:	additive incorporated in an asphalt concrete to alleviate its stripping potential (physical separation of asphalt cement from aggregate, primarily due to moisture action).
armour stone:	large angular blocks of quarry stone used for erosion control and wave protection of marine structures such as breakwaters.
asphalt:	dark brown to black cementitious material in which the predominating constituents are bitumens that occur in nature or are obtained during crude petroleum refining.
asphalt cement (AC):	asphalt that is refined to meet specifications for paving, industrial and special purposes (OPSS 1101).
asphalt concrete:	plant hot mixture of asphalt cement and well-graded aggregate (HMA), placed and compacted into a dense mat in construction of asphalt pavement (OPSS 1150).
asphalt recycling agent:	petroleum product additive, such as flux oil, used to restore aged asphalt cement to desired specification.
asphalt pavement:	pavement consisting of surface and binder course asphalt concrete on supporting courses such as concrete base (composite pavement), asphalt treated base, cement treated base, granular base and/or granular subbase placed over the subgrade.
asphalt pavement surface recycling:	see hot in-place recycling.
base course:	layer of material immediately beneath the asphalt concrete or portland cement concrete surface of a pavement. (See asphalt pavement for instance.)
binder course:	the lower asphalt concrete course(s) of a pavement.
blast furnace slag:	nonmetallic byproduct of iron production in blast furnaces, consisting essentially of silicates and alumina-silicates of lime and other bases. Depending on the method of cooling the liquid slag, four types of blast furnace slag are produced: (1) air-cooled (solidification under ambient conditions), which finds extensive use in conventional aggregate applications; (2) expanded or foamed (solidified with controlled quantities of water, sometimes with air or steam), which is mainly used as a lightweight aggregate; (3) granulated (solidified by quick water-quenching to a

glassy state), which is mainly used in slag cement manufacture; and (4) pelletized (solidified by water and air-quenching in conjunction with a spinning drum), which is used both as a lightweight aggregate and in slag cement manufacture.

blended cement

(blended hydraulic cement): intimate blend (interground and/or uniform blending) of portland cement with ground granulated blast furnace slag, fly ash or silica fume, in accordance with CSA Standard A362: (1) Type 10S - Portland Blast Furnace Slag; (2) Type 10SM - Slag-Modified Portland; (3) Type 10F - Portland Fly Ash; (4) Type 10FM - Fly Ash-Modified Portland; and (5) Type 10SF - Portland Silica Fume. (See supplementary cementing materials also.)

boiler slag: molten ash from high temperature pulverized coal burning power plants that is water quenched forming angular, black, 'glassy' particles.

bottom ash: ash particles from pulverized coal burning power plants that clinker together and fall to the bottom of the furnace to cool.

byproduct: secondary or incidental product to primary production material.

byproduct calcium sulphate: calcium sulphate obtained as a byproduct of a number of chemical processes as anhydrite (CaSO_4), hemihydrate ($\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$) or gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). (See scrubber sludge also.)

carbide lime: byproduct lime from the manufacture of acetylene.

cement: portland cement (PC, CSA Standard A5) or blended cement (blended hydraulic cement, CSA Standard A362).

coarse aggregate: aggregate that is predominantly retained on the 4.75 mm sieve size.

cold recycling (cold asphalt pavement recycling): full or partial depth reuse of old asphalt concrete pavement (can be used for surface treatment, and can include treated and untreated base) that is either processed in-place or at a central plant, typically with the addition of emulsified asphalt (or other additive such as cutback asphalt, lime or cement) to achieve desired cold mix quality, followed by placement and compaction.

concrete (portland cement concrete, PCC): composite material consisting essentially of a mixture of cement and water (binding paste) with which are mixed particles of fine and coarse aggregates (CSA A23.1).

concrete recycling: reuse of old concrete (PCC) such as foundation elements and pavements by processing into aggregates for use in place of, or mixed with, conventional aggregates in applications such as trench bedding, granular base, treated base, asphalt concrete (HMA) and concrete (PCC).

copper slag: byproduct slag from primary copper smelting furnace that is either air-cooled (dark, porous appearance) or granulated (black, angular, glassy appearance).

crushed gravel: aggregate, from crushing of gravel, with substantially all particles having at least one fractured (crushed) face. (Various agency specifications will have specific crushed material definitions and requirements to meet for various aggregate applications, OPSS 1003 for instance.)

crushed stone: aggregate, from crushing of quarried rock, with all faces fractured (crushed).

crusher run: aggregate, from a crushing plant, that has not been screened into various sizes.

cullet:	scrap glass, usually crushed for reuse.
cutback asphalt (liquid asphalt):	asphalt cement which has been liquefied by blending with petroleum solvents, which evaporate upon exposure to atmospheric conditions, leaving the asphalt cement to perform its cementing function (OPSS 1102).
demolition waste (building rubble):	material, resulting from the demolition of building elements such as walls, floors and foundations, generally in a rubble form consisting mainly of concrete, brick, plaster, wood, steel and piping.
emulsified asphalt:	anionic or cationic emulsion of asphalt cement and water that contains a small amount of an emulsifying agent, which sets by water separation/ evaporation and/or chemically, leaving the asphalt cement to perform its cementing function (OPSS 1103).
excess material:	rock, earth, aggregate, old asphalt concrete, old concrete, wood, etc., resulting from construction, that cannot be used at the site.
fill:	material placed to level or raise the height of a site.
fine aggregate:	aggregate that predominantly passes the 4.75 mm sieve size and is retained on the 75 µm sieve size.
flux oil:	thick, relatively nonvolatile fraction of petroleum which may be used to soften asphalt to a desired consistency.
fly ash (pulverized fuel ash, PFA):	siliceous, fine, solid particles, from pulverized coal burning power plants, carried upwards by the combustion gases and collected in air emission control equipment (electrostatic precipitators).
foundry sand (spent sand, waste sand):	silica sand used in ferrous and nonferrous foundries in the moulds, that becomes 'contaminated' during the casting process, and is reused, regenerated (recycled) or wasted.
full depth recycling:	full thickness of old asphalt concrete or concrete (PCC) processed and recycled.
furnace clinker:	residue from lump coal combustion on travelling grates or from retort stoker firing used in older power stations, relatively scarce with conversion to pulverized coal.
glass:	vitreous material from the fusion of silica sand and soda ash with additional ingredients such as cullet and colouring additives.
Glasphalt:	hot-mix asphalt concrete (HMA) in which processed waste glass (unrecyclable glass) replaces some of the aggregates (bonding/antistripping additive of about one percent hydrated lime typically required).
granular:	aggregate used in granular base, granular subbase or select subgrade (OPSS 1010).
gravel:	granular material consisting of rounded, water-worn rock fragments 2 mm to 75 mm in size usually intermixed with sand.
hot asphalt pavement recycling (hot-mix recycling, recycled hot mix, RHM):	removal (surface milling or full depth) of old asphalt concrete (reclaimed asphalt pavement, RAP), processing, heating and mixing in a hot-mix plant (batch, drum or

	drum/batch) with new aggregates and new asphalt cement (softer grade or with recycling agent), relaying and compacting to meet specifications for conventional hot mix asphalt concrete (HMA).
hot-mix asphalt concrete (hot mix, hot-mix asphalt, HMA):	designed aggregate and asphalt cement mix produced in a hot-mix plant (batch, drum or drum/batch) where the aggregates are dried, heated and then mixed with heated (fluid) asphalt cement (hot mix), then transported, placed and compacted while still at an elevated temperature (about 125 to 135 °C) to give a durable, deformation resistant, fatigue resistant pavement course.
hot in-place recycling (asphalt pavement surface recycling):	hot reworking of the surface of an aged asphalt pavement (typically up to 50 mm) using preheaters and a heat reforming machine, typically with the addition of a rejuvenator, aggregate or new hot mix (HMA) to restore the condition of the scarified old asphalt pavement, and sometimes with an integral surface course overlay, all suitably placed and compacted in a single or multi-pass process.
kiln dust (cement and lime kiln dust):	dust particles generated from the calcining of raw materials in kilns, during the manufacture of cement or lime, that are carried out by the exit gases and captured in dust collection systems.
lime:	all classes of calcitic (high calcium) and dolomitic quicklime and hydrated lime.
limestone:	sedimentary rock composed principally of calcium carbonate (calcite) or the double carbonate of calcium and magnesium (dolomite).
manufactured sand:	fine aggregate produced by the crushing and processing (does not include screenings) of quarried rock or boulders, cobbles and gravel from which the natural fine aggregate has been removed (OPSS 1001).
materials recovery:	initial phase of waste processing in which recyclable materials are extracted.
milling (cold planing):	removing surface of an asphalt concrete pavement, using a travelling machine equipped with a transverse rotating cutter drum (milling head with tips), typically 25 to 75 mm in depth. The resulting asphalt concrete millings (form of reclaimed asphalt pavement, RAP) are usually recycled.
mill tailings (tailings):	finely divided materials, which are discarded, from the concentration and recovery of mineral values from ores.
mineral filler:	finely divided mineral product, at least 70 percent of which passes the 75 µm sieve size (hot-mix asphalt use), such as pulverized limestone (most common manufactured filler). (The term 'filler' is often used with hot-mix asphalt for all of the minus 75 µm sieve size material.)
nickel slag:	iron-silicate slag byproduct of nickel production that is either ambient cooled (dark, porous) or granulated (black, angular, glassy appearance), very similar to copper slag.
pavement structure:	all courses (components) of a pavement above the subgrade to the traffic surface such as granular subbase, granular base, treated (asphalt or cement) base, asphalt concrete (HMA) and concrete (PCC).

pozzolan:	siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide to form compounds having cementitious properties.
portland cement concrete (PCC):	see concrete.
portland cement concrete recycling:	see concrete recycling.
reclaimed aggregate material (RAM):	removed and/or processed pavement materials containing no reusable asphalt cement.
reclaimed asphalt pavement (RAP):	removed and/or processed pavement materials containing asphalt cement and aggregates.
reclaimed concrete (reclaimed concrete material, RCM):	removed and/or processed old portland cement concrete (PCC).
recycling:	when material is reclaimed from the waste stream and put to some use after varying degrees of processing.
recycled hot mix (RHM):	hot-mix asphalt concrete that contains processed reclaimed asphalt pavement (RAP). (See hot asphalt pavement recycling.)
residue:	material remaining after completion of a chemical or physical process such as combustion, evaporation, distillation or filtration.
resource conservation:	combination of waste reduction, reuse and recycling (sometimes termed the 3 Rs).
resource recovery:	extraction and use of material(s) from a waste stream.
reuse:	when material is reclaimed from the waste stream and put to some use with little or no processing.
reworking:	processing existing unbound pavement materials in place, such as granular base, mechanically and/or by stabilization to improve performance.
rubble:	see demolition waste.
sand:	fine aggregate resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone. (See manufactured sand and screenings.)
screenings:	fine aggregate including dust (minus 75 μm) produced by the crushing of quarried rock or boulders, cobbles and gravel from which the natural fine aggregate has been removed. (Typically a byproduct of crushing and processing quarried rock or gravel for asphalt and concrete coarse aggregates.)
scrubber sludge:	sludge waste from the use of lime or limestone in a gaseous emissions scrubber system to remove sulphur dioxide (power plants for instance). (See byproduct calcium sulphate.)
silica fume:	finely divided residue, resulting from the production of silicon or silicon-containing alloys, which is carried from the production furnace with the exhaust gases and collected in the air emission control equipment (electrostatic precipitators).

slag cement:	• see supplementary cementing materials.
slag:	molten byproducts, from the smelting or sintering of metallic ores, that are cooled by various methods.
sludge:	material in the form of a concentrated suspension of solids in liquid.
solid waste management:	conduct and regulation of the entire process of generation, storage, collection, transportation, processing, reduction, reuse, recovery and disposal of solid waste.
steel slag:	byproduct slag, that is developed simultaneously with steel in basic oxygen, electric, and open hearth (few now in use) steelmaking furnaces, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium, including foreign materials such as unhydrated lime (free CaO) that require special treatment before use.
stone:	any natural rock deposit or formation of igneous, sedimentary and/or metamorphic origin, usually used as dimension stone or crushed stone in building or road construction.
subbase course:	layer of material in a pavement immediately above the subgrade. (See asphalt pavement for instance.)
subgrade:	soil prepared through cut, fill and/or fine dressing to support a pavement. (See asphalt pavement for instance.)
supplementary cementing materials:	material that, when used in conjunction with portland cement, contributes to the properties of the hardened concrete through hydraulic and/or pozzolanic activity, in accordance with CSA Standards A23.5 and A363: (1) Type N - Natural pozzolan; (2) Type F - Class F fly ash (normally from burning anthracite or bituminous coal); (3) Type C - Class C fly ash (normally from burning lignite or sub-bituminous coal); (4) Type G - Ground granulated blast furnace slag; (5) Type H - Cementitious hydraulic slag (CSA Standard A363); and (6) Type U - Silica fume.
surface course:	top hot-mix asphalt course (HMA) of a pavement, sometimes called asphalt wearing course. (See asphalt pavement for instance.)
sustainable development:	using natural resources in such a way as to meet current economic and social needs, but not depleting or degrading these resources to the point that they cannot meet these needs for future generations.
tailings:	see mill tailings.
waste:	wide variety of materials which are discarded or rejected as being spent, useless, worthless or in excess.
waste rock:	coarse material which is broken and removed during quarrying or mining operations to expose the usable rock or ore, respectively.

APPENDIX B

SPECIFICATIONS

B 1. GENERAL

The largest use for wastes and byproducts as aggregates appears to be in transportation facilities construction and maintenance applications such as engineered fill, ballast, pipe bedding, subbase, base, shouldering and recycled cold and hot mixes (RHM)*. Ontario Provincial Standard Specifications (OPSS) for construction and materials supplemented by other standards (American Society for Testing and Materials (ASTM) for instance, and particularly Canadian Standards Association (CSA) in the case of cement and concrete) and special provisions based on local experience, are widely adopted for conventional aggregates use in pavement construction and other infrastructure work. There are currently only a few additional Ontario specifications that have been specifically developed for the reuse and recycling of wastes and byproducts as aggregates. This is undoubtedly due to users not unreasonably requiring wastes and byproducts used as aggregates to meet relevant standard specifications.

A comprehensive listing of specifications and references for aggregate and cementitious reuse and recycling of wastes and byproducts is given in the reference section of this Appendix. It is important that the full specifications for an intended aggregate or cementitious use be checked to ensure that the waste or byproduct is technically suitable. This will undoubtedly also require detailed characterization of the waste or byproduct, particularly when considering a new use. For instance, aggregate for use in subbase must meet both gradation and physical requirements such as maximum Los Angeles abrasion loss, maximum petrographic number, maximum plasticity index and minimum crushed content. It should also be recognized that some specific byproducts such as blast furnace slag and traprock are considered by OPSS to be conventional aggregates.

B 2. USE OF AGGREGATES IN PAVEMENTS

B 2.1 General

The use of aggregates in pavements will be adopted to illustrate the general aggregates technology involved as: large amounts of conventional aggregates are used in pavement construction and maintenance (granular subbase, granular base, asphalt concrete surfacing, etc.); use of wastes and byproducts as aggregates in pavements is increasing (old asphalt concrete (RAP), air-cooled blast furnace slag, etc.); and pavement materials specifications (OPSS** across Ontario for instance) provide a wide range of practical applications guidance. Much of the information presented on the use of aggregates in pavements is based on Ontario experience and the Ministry of Transportation (MTO) "Pavement Design and Rehabilitation Manual"*** which JEGEL has been involved with during preparation and presentations. Emphasis will be placed on flexible (asphalt) pavements as they make up the greatest part of the road/highway network.

B 2.2 Pavement Structures

Typical conventional pavement structures (Figure B1) are made up of layers of granular subbase, granular base and surfacing, designed to support the traffic loadings (magnitude and replications) for the site subgrade and environmental conditions. The pavement surface is normally hot-mix asphalt concrete (HMA), portland cement concrete (PCC), plant or road-mixed mulch, cold mix or surface treatment.

Depending on the specific technically-sound, cost-effective design adopted (influence of local soil conditions for instance), the granular subbase and/or base may be omitted or replaced with cement treated, asphalt treated or lean concrete base, or an open-graded drainage layer. In composite pavements, the PCC base forms part of the pavement. The subgrade may also be improved (stabilized) with materials such as lime and fly ash.

*See Appendix A for definitions.

**See Sections B2. and B3. of this Appendix for specification references and sources.

B 2.2.1 Functions and Characteristics of Flexible Pavement Structure Layers

(A PCC surface distributes load stresses in addition to acting as a wearing surface.)

Wearing Course - Generally a dense, highly stable, durable, good frictional properties surface course HMA which carries the traffic. It must resist the elements and keep water out of the underlying materials. The surface course HMA type is selected on the basis of its wearing, durability, friction and strength properties.

Binder Course - Lower layer(s) of HMA. It is normally distinguished from the surface course when there is a difference in the quality of the hot mixes used. It adds much to the overall strength of the pavement structure, supports the surface course and distributes load to the base.

The following mechanical properties are of importance to the performance of HMA:

1. elastic stiffness;
2. resistance to fatigue cracking; and
3. resistance to permanent deformation (rutting).

Granular Base Course - Carries a large portion of the load, provides some drainage, minimizes frost action and allows fine grading for surfacing. It is generally specified as high stability, graded, crushed gravel or stone.

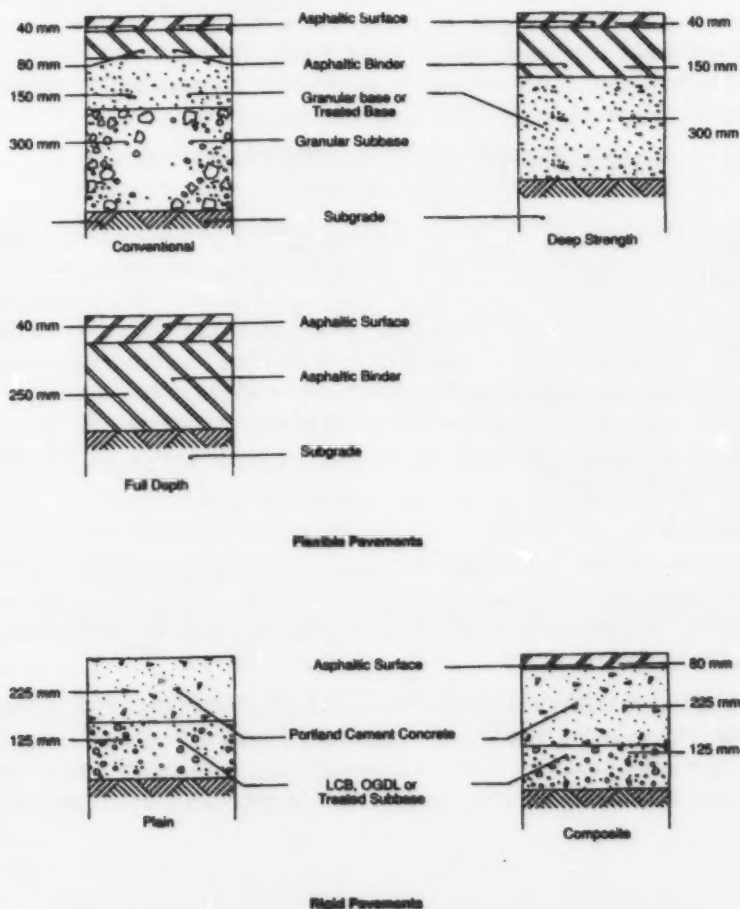


FIGURE B1 FLEXIBLE AND RIGID PAVEMENT STRUCTURES
(Adapted from MTO Pavement Design and Rehabilitation Manual.)

Granular Subbase Course - Normally a non-processed aggregate obtained from local gravel pits. Performs the same function as a granular base course except that it can be of lower quality.

Subgrade - This is the 'foundation' for both flexible and rigid pavement structures. It is the uppermost material placed in embankments or remaining in cuts. It carries the pavement structure and distributed wheel load stresses.

B 2.3 General Requirements for Aggregates in Pavements

Aggregates for use in granular subbase, granular base, treated base, HMA, PCC, etc. must be carefully specified/selected to perform satisfactorily in terms of function (vehicle load stresses for instance) and durability (frost resistance for instance). The Ontario grading and physical requirements for aggregates in pavements and transportation structures are typically based on MTO test procedures (LS), which simulate field conditions, and OPSS reflecting practical MTO usage experience: Los Angeles impact and abrasion test (MTO LS603, ASTM C131); magnesium sulphate soundness test (MTO LS606, ASTM C88); 24-hour water absorption test (MTO LS604, ASTM C127); and petrographic evaluation leading to a petrographic number (PN, MTO LS609). (See Senior and Rogers, 1990, for a comprehensive review of MTO methods for predicting aggregate performance.)

The petrographic evaluation (PN) of an aggregate, or waste/byproduct being considered for use, is considered to give a good general indication of potential suitability and performance. The petrographic evaluation (PN) is a routine, subjective quality test for coarse aggregate used to assess soundness, durability, hardness and strength. Simple index tests are used to classify the individual aggregate particles into quality types according to rock type, strength, hardness, and degree of weathering. Four quality categories are recognized: good aggregate (Factor 1); fair aggregate (Factor 3); poor aggregate (Factor 6); and deleterious aggregate (Factor 10). A petrographic number (PN) is calculated by multiplying the percentages of each group by the appropriate factor and adding up to arrive at the total PN. The higher the PN, the lower the quality of the aggregate. The weighting factors for certain categories of aggregates are different, depending on whether the aggregate will be used for HMA, PCC or granular material.

While MTO experience indicates the PN to be an essential procedure in the evaluation of aggregate quality, there are problems with the Los Angeles abrasion test and magnesium soundness test in terms of precision and correlation with aggregate field performance. In summary, MTO experience indicates that:

1. the likely performance of aggregates in granular base is best measured by the micro-Deval test (a form of abrasion test in a ball mill) and water absorption;
2. the physical performance of concrete aggregates is best measured by the micro-Deval test, water absorption and unconfined freezing and thawing (other tests such as alkali reactivity are very important);
3. the performance of asphalt concrete aggregates is best measured by the micro-Deval test, polished stone value test and unconfined freezing and thawing; and
4. petrographic examination is also an essential tool in the evaluation of aggregate quality.

It appears that the MTO will be adopting the micro-Deval and unconfined freezing and thawing tests over the next few years.

B 2.4 Granular Materials

B 2.4.1 Granular Base

Each agency will have a range of specified granular materials, such as the MTO four granular materials (Granular A, B, M and SSM) in Table B1, where physical and gradation requirements are given.

Granular A - relatively fine, well-graded, high-crushed fraction, that can be compacted to a dense stable material that can be fine graded. Specified as base course and shouldering material, as well as surface course for some rural roads. (Granular A is generally not free draining.)

Granular B, Type I - coarser and wider gradation than Granular A and not required to have crushed fraction. Thus, generally not as stable as Granular A and specified as subbase course.

Granular B, Type II - crushed material, with a tighter gradation, used where Type I is not available and/or use of a higher quality subbase course is required. (Granular B is generally not free draining.)

Granular M - same physical requirements as Granular A but finer gradation. Low susceptibility to segregation and can be fine graded for shoulder and granular road maintenance.

Select Subgrade Material (SSM) - sand, to sand and gravel sized material, that is non-plastic. Generally a good quality fill and backfill, although lower performance characteristics than Granular A, B and M. In some cases, local fine sand can be used to achieve uniform subgrade performance and eliminate/reduce the need for subbase.

**TABLE B1 ONTARIO PROVINCIAL STANDARD SPECIFICATION (OPSS 1010)
REQUIREMENTS FOR GRANULAR MATERIALS**

PHYSICAL REQUIREMENTS

PHYSICAL TEST	GRANULAR A	GRANULAR B TYPE I TYPE II		GRANULAR M	SELECT SUBGRADE MATERIAL	MTO LABORATORY TEST NUMBER
Los Angeles Abrasion						
Loss, %, Maximum	60	N/A	N/A	60	N/A	LS 603
Petrographic Number						
Maximum	200	250*	250	200	250*	LS 609
Plasticity Index	0	0	0	0	0	LS 704
Percentage Crushed						
Minimum	50	N/A	100	50	N/A	LS 607

*The petrographic number (PN) requirement is waived if the material has more than 80 percent passing the 4.75 mm sieve size.

GRADATION REQUIREMENTS*
Percentage Passing by Mass**

MTO SIEVE SIZE	GRANULAR A	GRANULAR B		GRANULAR M	SELECT SUBGRADE MATERIAL
		TYPE I	TYPE II		
150 mm	N/A	100	100	N/A	100
37.5 mm	N/A	N/A	N/A	N/A	N/A
26.5 mm	100	50-100	50-100	N/A	50-100
19 mm	85-100 (87-100)*	N/A	N/A	100	N/A
13.2 mm	65-90 (75-95)*	N/A	N/A	75-95	N/A
9.5 mm	50-73 (60-83)*	N/A	N/A	55-80	N/A
4.75 mm	35-55 (40-60)*	20-100	20-55	35-55	20-100
1.18 mm	15-40	10-100	10-40	15-40	10-100
300 µm	5-22	2-65	5-22	5-22	5-95
150 µm	N/A	N/A	N/A	N/A	2-65
75 µm	2-8 (2-10)**	0-80 (0-10)**	0-10 (2-10)**	2-8	0-25

*Where the aggregate is obtained from a blast furnace slag source.

**Where the aggregate is obtained from a quarry or suitable slag source.

***MTO Laboratory Test Number LS 602.

NOTE: When Granular B is used for granular backfill for pipe subdrains, 100 percent of the material must pass the 37.5 mm sieve size.

In addition to the above, free draining, open-graded granular base (untreated, cement treated or typically asphalt treated, OGDL) is now being adopted by the MTO and other agencies in Ontario. The OGDL aggregate is essentially 100 percent crushed coarse aggregate with a low minus 75 μm content (less than about four percent).

B 2.4.2 Treated Granular Bases

Granular materials can be treated with a number of additives to enhance their engineering properties. The majority of such treatments are undertaken to improve granular strength and stability under loading. Granular materials are also treated with additives to control dust or to reduce settlement. The three major material groups of additives for granular treatment are: portland cement; asphalts; and others (flyash/ lime, calcium chloride, lignosulphonate, etc.)

Cement treated base (CTB - about 5 percent portland cement), lean concrete base (LCB - about 7 percent portland cement) and roller compacted concrete (RCC - about 12 to 14 percent portland cement, zero slump) are terms used to describe three types of portland cement treatment which are used to improve the stability of granular materials. It is important that the durability of CTB be checked for salt and freeze-thaw resistance.

Asphalt treatment of granular base materials improves the stability of the granular materials as well as providing increased resistance to the penetration of water. Bituminous treated base (BTB), as used by the MTO, consists of Granular A mixed with 3 to 3.5 percent asphalt cement in a central plant and placed with an asphalt spreader. In the short term, BTB provides an adequate wearing surface, however, due to its low asphalt cement content, it should be overlaid with hot-mix asphalt concrete to prevent ravelling. Emulsion Stabilized Base (ESB) is also used.

B 2.4.3 Unshrinkable Fill

Unshrinkable fill (controlled density backfill) is a fluid mix of sand, aggregate and a low percentage of portland cement (about 25 kg/m³). The design compressive strength of the mix is typically 0.4 MPa at 28 days. The mix is used as trench backfill where settlement cannot be tolerated and to restore utility cuts on existing roads. Although the material cost of unshrinkable fill is higher than that of granular backfill, the ease of placement and the reduced maintenance costs over the long term can provide a cost-effective alternative to properly placed and compacted granular backfill. The use of unshrinkable fill in trenches where frost-susceptible material is present is not recommended since non-uniform road performance may result.

B 2.4.4 Cementitious Fly Ash Grout

Cementitious fly ash grout has been used to fill voids beneath PCC pavements. This subsealing is required to fill voids at joints under PCC pavements where fines have been lost due to pumping. In the past, remedial action consisted of overlaying the joints, however this repair method did not prevent the deflection of the slab and consequently progressive cracking and deterioration of the joints often occurred.

The performance requirements of the grout are that it be insoluble, incompressible, non-erodible, strong, flowable and unshrinkable. Fly ash portland cement grouts, when compared to 100 percent portland cement grout, have superior flow properties. Due to its relative fineness and spherical shape, the fly ash grout can penetrate very small voids and achieve greater subsealing than with a portland cement grout. In experiments carried out by the MTO, grout using Type C fly ash was found to be superior in terms of strength and shrinkage when compared to Type F fly ash. The mix used by the MTO in field trials consisted of 1 part cement, 3 parts Type C fly ash and 4.4 parts water.

B 2.4.5 Lightweight Fill

Lightweight fill has been used in the construction of embankments over soft, compressible soil where long-term settlements resulting from the use of normal fill would not be tolerable. The MTO has used sawdust, expanded polystyrene (styrofoam) and blast furnace slag (air-cooled and pelletized) as lightweight fill.

Sawdust has been used successfully in northern Ontario for the crossing of swamps. A woven geotextile is placed directly onto the swamp surface, transverse to the road direction. Sawdust is then end dumped onto the geotextile to the elevation of the design profile after which the ends of the geotextile are wrapped over the top of the sawdust.

Placement of the sawdust to the design profile takes into account that some settlement will occur. Experience indicates that provided the sawdust remains below the water surface its decomposition rate will be very slow.

Air-cooled and pelletized blast furnace slag is a lightweight byproduct of the iron/steel industry. The slag is 20 to 40 percent lighter than normal backfill as a result of voids within the slag particles. Air-cooled blast furnace slag is a gravel to cobble sized material which may be used as fill without processing, or it may be crushed. The slag is placed and compacted in a manner similar to conventional aggregate fill. During the first week to two after production, the slag may emit a sulphurous effluent and odour when contacted with water. Therefore the use of air-cooled blast furnace slag in fills should be avoided. Air-cooled blast furnace slag must be differentiated from nickel or steel slags which are not used as lightweight fill.

B 2.5 Asphalt Materials

Asphalt materials include a wide range of plant and road mixed materials comprising asphalt binder (asphalt cement, cutback asphalt or emulsified asphalt) and aggregates, with the following general properties:

1. resistance to surface wear;
2. reduced surface water infiltration;
3. smooth and rideable finish; and
4. structural support of wheel loads.

The MTO defines two broad classes of asphalt pavement surfaces:

1. Mix Systems
 - hot and cold mixed asphalt concrete
 - hot and cold mixed stabilized base
 - recycled hot and cold mixed asphalt concrete
 - ravel plant cold mix
 - slurry seal
2. Layered Systems
 - penetration primer
 - surface treatment
 - macadam

Specific road/highway use, economic considerations and the functional requirements of the pavement type determine which asphalt material should be used to surface a road. The material and construction requirements for asphalt materials are typically covered by agency specifications (OPSS for instance).

B 2.5.1 Hot-Mix Asphalt Concrete

Hot-mix asphalt concrete (HMA) is a designed (typically Marshall method) mix of coarse and fine aggregates with asphalt cement binder which is mixed, placed and compacted in a heated condition. The MTO specifies (OPSS) a number of hot mix types:

HL 1 - dense-graded surface course mix, with a premium quality coarse aggregate (excellent frictional and wear properties, maximum 16 mm size), used on high-traffic volume highways.

HL 2 - sand mix (minus 9.5 mm) used as a levelling course, thin overlay on low speed areas and to fill wide cracks.

HL 3 - dense-graded surface course mix with aggregate gradation the same as HL 1 and lower physical properties requirements.

HL 3 Fine - fine, dense-graded surface course mix (minus 16 mm) used for hand work areas, minor municipal roads, driveways, boulevards, parking areas, etc.

HL 4 - dense-graded surface or binder course mix (minus 19 mm).

HL 8 - dense-graded binder course mix (minus 26.5 mm).

Heavy Duty Binder - dense-graded, high-stability binder course mix designed to resist rutting (100 percent crushed coarse and fine aggregates, HL 4 or HL 8 gradation).

Dense Friction Course (DFC) - dense-graded, premium surface course mix, with high frictional resistance (HL 1 gradation, physical properties of coarse and fine aggregates superior, trap rock for instance), used for high-speed, high-traffic volume highways.

Open Friction Course - open-graded, premium surface course mix, with superior quality aggregates, used in place of DFC where low tire noise desired (free draining with good frictional resistance).

Modified Mixes - hot mixes modified to suit required performance or the availability of materials (HL 4 Mod and HL 8 Mod are open-graded, well-draining binder course mixes for instance).

The types of coarse and fine aggregates used in HMA surface course mixes are summarized in Table B2.

B 2.5.2 Cold-Mix Asphalt Concrete

Cold mix is a mixture of emulsified asphalt and aggregates produced, placed and compacted at ambient temperature. Liquid asphalt (cutback) is also used, however emulsified asphalt is normally specified due to its lower cost. The use of cold mix is generally restricted to low-volume roads, where hot-mix asphalt concrete surfaced pavements are not required. Cold mix asphalt concrete (dense or open-graded) can be mixed in a central plant or in-place on the road surface with a travelling mixer (Midland Mix Paver (Section B 2.7.5) and road mix mulch pavements). Once the emulsified asphalt in the mixture surface starts to break, or set, the mixture is compacted. Open-graded mixes are relatively stony mixes containing less than 10 percent fine aggregate. Open-graded mixes are more commonly used than dense-graded mixes due to some difficulty in attaining uniform coating of the coarse aggregates in dense-graded mixes. The open-graded mixes are surfaced with a light choke-sand coating to seal the surface and to minimize aggregate pick-out by traffic. The mix surface is normally covered within a year with a single surface treatment (SST).

TABLE B2 COARSE AND FINE AGGREGATE SOURCES FOR SURFACE COURSE HMA
(Must be on Designated Source List and/or Aggregate Source List.)

TYPE	TRAP ROCK	STEEL SLAG	BLAST FURNACE SLAG	GRAVEL	DOLOMITIC SANDSTONE
HL 1 Coarse	X	X	X	X	
HL 1 Fine			LOCAL	AGGREGATE	
DFC Coarse	X	X	X		
DFC Fine	X	X	X		
OFC Coarse	X	X			
OFC Fine	X	X			
HL 3 Coarse	X	X	X	X	X
HL 3 Fine	X	X	X	X	X

Note: It is very important that specific contract requirements, current specifications, and current source lists be checked for each project.

B 2.5.3 Surface Treatments

Surface treatments consist of an application of emulsified or cutback asphalt and select aggregate over a prepared granular base or existing surface. Following placement of the aggregate, the mixture is rolled and compacted to provide a driveable and dust-free surface. Emulsified asphalt is more commonly used than cutback asphalt due to its lower cost. This type of pavement surface is frequently used on light to medium volume roads which may or may not have an existing asphalt concrete surface cover. Surface treatment of a granular road serves to control the infiltration of water, provide frictional resistance, improve ride quality, and control dust and stone pick-up. Surface

treatments are also applied over existing surface treated or asphalt concrete pavements to restore frictional resistance and reduce the infiltration of water. Surface treatment type selection and application rate are based on the traffic volume and existing road surface characteristics.

B 2.5.4 Other Asphalt Surface Treatments

Other types of asphalt surface treatments include mulch pavement, slurry seal, fog seal, primer, tack coat and granular sealing.

Slurry seal is a mixture of emulsified asphalt, well graded fine aggregate and mineral filler (cement for instance) applied in 3 to 6 mm layers. Slurry seal is applied over existing asphalt concrete pavement and is used to seal the pavement and prevent ravelling. It provides no structural strength. Slurry seal is generally applied to the pavement surface from a travelling plant via a spreader box. This treatment is predominantly used by urban municipalities. As an extension to conventional slurry seals, micro-surfacing (crushed aggregate/polymer modified emulsion slurry seal) use is developing in Ontario.

B 2.6 Portland Cement Concrete

Portland cement concrete (PCC) is a mixture of sand and gravel or crushed stone bonded by a hardened paste of portland cement and water (additives for workability, air-entraining, etc. are typically used). Portland cement concrete mixes are normally designed by the ready mix supplier/contractor to OPSS requirements. The characteristics of PCC which influence its placement and performance are:

1. **workability** - must be workable so that it can be placed and consolidated without excessive segregation or bleeding;
2. **curing rate** - must harden at a sufficient rate to allow use at the earliest time (for new PCC pavement construction the curing rate is normally several days);
3. **strength** - must develop sufficient strength to support the design loads. PCC pavements normally are specified to have a nominal design compressive strength of 25 MPa. Traffic can be allowed on the road when the concrete has a strength of 15 MPa. Flexural or splitting tensile strength requirements are also normally given. A typical specified minimum splitting tensile strength is 2.8 MPa at 10 days.
4. **durability** - must be able to withstand free-thaw cycles and the service environment; and
5. **volume stability** - must not experience severe volume change during curing or service life in order to minimize the potential for cracking and deterioration.

Properties of PCC which are of particular importance to pavement performance are durability and flexural strength. PCC should be of sufficient durability to resist the effects of freeze-thaw, salt penetration, sulphate attack and traffic abrasion. Flexural strength refers to the bending strength of the concrete required to support both the magnitude of the wheel loads and the number of load applications. These aspects of concrete behaviour and design are critical to concrete pavement performance.

B 2.7 Pavement Rehabilitation

B 2.7.1 Hot-Mix Resurfacing

When a flexible pavement's serviceability (quality) becomes lower with use than considered to be the minimum acceptable level, and routine and major maintenance activities are not able to adequately address the problems, rehabilitation of the pavement will be necessary. The recommended rehabilitation alternatives for each road will be dependent upon the riding quality and the type of distress(es) evident, its cause(s) and severity, as well as operational and planning considerations.

Hot-mix resurfacing, in conjunction with other improvements, is a widely adopted principal rehabilitation alternative. The overlay thickness required will depend on the ride and structural condition of the existing roadway. Where settlements and distortions of the road surface preclude placement of a smooth overlay, prior padding or

milling may be necessary. Consideration must also be given to treatment of any cracks or other deficiencies prior to the resurfacing.

B 2.7.2 Partial-Depth Removal and Hot-Mix Resurfacing

The structural condition of the pavement may be acceptable, however, aging of the surface or surficial defects such as ravelling, segregation and stripping may dictate partial-depth removal and replacement of the asphalt concrete with hot mix or recycled hot mix. Partial-depth removal and replacement may be necessary where the existing curb and gutter, catchbasins or drainage will not permit raising of the pavement surface. Partial-depth removal is normally accomplished using cold-milling equipment. The material (RAP) removed from the existing pavement surface may be transported to a central plant for processing and recycling.

B 2.7.3 In-Place Recycling

In-place recycling involves scarification of the existing pavement surface, in-place processing of the scarified materials, possibly adding binder (with or without additives to improve the binder properties) and simultaneous placement of the processed material. This operation can be completed by several different methods and various types of equipment, either hot or cold. Regardless of the process selected, candidate sections for in-place recycling should be thoroughly evaluated and the properties of the existing asphalt concrete determined (aggregate characteristics and asphalt cement properties in particular), noting that the finished in-place recycled pavement quality will be largely dependent upon these features. For example, if the existing surface exhibits distresses associated with poor aggregates, an in-place recycled pavement will also exhibit similar problems.

Cold in-place recycling consists of cold milling the existing pavement surface and mixing with emulsified asphalt (possibly in conjunction with modifiers to improve/restore the former, aged asphalt cement properties). Integrated equipment trains are now available for this process.

Hot in-place recycling consists of heating the existing asphaltic concrete surface, scarification (with mixing and possible addition of new materials and rejuvenating agents in some processes) and reprofiling to produce a recycled asphalt pavement of comparable quality to plant recycled hot mix. Some processes are capable of simultaneous in-place recycling followed by an integral hot-mix overlay in a single operation.

B 2.7.4 Full-Depth Removal and Replacement with Recycled Hot Mix (RHM)

Where the existing asphalt concrete is too distressed to overlay and too thin (approximately 80 mm) to be considered for in-place recycling, full-depth removal and replacement with recycled hot mix (RHM) should be considered. The existing asphalt is removed by a variety of methods, including milling and ripping, and transported to a central asphalt plant site. The reclaimed asphalt concrete (RAP) is crushed at the plant site to the appropriate size then stockpiled for recycling in the asphalt plant. The exposed granular base can be reshaped after removing the asphalt concrete, strengthened with additional granular base as necessary, and then surfaced using RHM.

B 2.7.5 Cold Mix with Sealed Surface Course (Midland Mix Paver)

Cold-laid mixes are produced either through a Midland Mix Paver or a central plant. The Midland Mix Paver comprises a mobile plant which mixes and places aggregate and emulsified asphalt. Aggregate is delivered to the site by truck and dumped into the paver hopper, similar to a conventional hot-mix paver. The aggregate is conveyed to a pugmill where it is sprayed with emulsified asphalt at a metered rate. The mix is then distributed across the roadway with rear augers and levelled using a vibratory screed. Both open-graded and dense-graded mixes can be constructed using this process, with the open-graded mixes generally being more successful due to better coating of the aggregates. The open-graded mix tends to ravel under higher traffic volumes and generally requires a seal coat over the cold-mix surface.

B 2.7.6 Surface Treatments

A surface treatment consists of a spray application of asphalt binder followed by the distribution of aggregates that are subsequently rolled into the binder. Surface treatments can be designated as single or double over a primed or unprimed surface. The selection of each depends on the traffic volumes, loads and operating speeds. Single surface treatments (over primed or previously surface treated roads) and double surface treatments (two applications of a single surface treatment) are used on low volume highways with generally less than 1000 AADT, and can employ a variety of binders and aggregate types depending on the desired characteristics of the finished surface.

B 2.7.7 Pulverization and Remixing Prior to Resurfacing

Pulverization and remixing involves pulverizing the existing pavement structure (up to 80 mm of asphalt concrete over granular base or 100 mm of surface treatment, or mulch, over granular base) to a maximum depth of 200 mm. This process thoroughly mixes the individual pavement layers into a relatively homogeneous mixture that can be compacted as granular base. Variations of the equipment allow for the introduction of emulsified asphalt, calcium chloride or other stabilizing agent during the mixing process to produce a stabilized base or shoulder.

B 3. TYPICAL SPECIFICATION PROVISIONS FOR WASTES AND BYPRODUCTS USE

B 3.1 Aggregate Uses

OPSS 1001* Aggregates - General

- slag included in lists of fine and coarse aggregates
- MTO tests for aggregates listed

OPSS 1002 Aggregates - Concrete

- coarse blast furnace slag (air-cooled) aggregate gradation and physical requirements
- ASTM lightweight aggregate requirements referenced which include expanded blast furnace slag aggregate

OPSS 1003 Aggregates - Asphaltic Concrete, Hot Mixed and Hot Laid

- slags included

OPSS 1010 Aggregates - Granular A, B, M and Select Subgrade Material

- crushed slag produced from iron blast furnace or blended nickel slag included for Granular A and M aggregates
- blast furnace slag, blended nickel slag and clinkers included for Type I Granular B aggregate
steel slag not permitted for Granular A, B, M or Select Subgrade Material

OPSS 1149 Asphaltic Concrete - Hot Mix and Hot Laid Including Recycled and Speciality Mixes

- recycled hot mix (RHM) incorporating reclaimed asphalt pavement (RAP) included
- steel slag (washed) and traprock included as fine and coarse aggregates² for open friction course mix (OFC)
- steel slag (washed, unless electric arc furnace source), blastfurnace slag and traprock included as fine and coarse aggregates** for dense friction course (DFC) and HL 1 mixes
- steel slag (washed) and traprock included as fine and coarse aggregates for heavy duty binder course mix (HDBC)
- OPSS 1149 is intended mainly for MTO use as it incorporates specific MTO materials selections, design, testing and payment requirements

MT 701 Specification for Hot Mix, Hot Laid Asphaltic Concrete (Metro Toronto)

- RHM binder course mix, HL 8 (RAP), incorporating up to 40 percent RAP included
- waste glass, up to 20 percent, permitted in HL 8 mix
- traprock, blast furnace slag and steel slag (washed) included as coarse and fine aggregates for DFC, HL 1 and HL 1A mixes

**See References in Section B3. for full citations and sources. It is important that specific contract requirements and current specifications are checked for each project.*

***Traprock, blast furnace slag and steel slag (washed) aggregates are generally included where good frictional properties and/or high stability is required in hot mixes.*

- steel slag (washed) included as coarse and fine aggregates in high stability binder course (HL 8 (HS)) mix
- the requirements for suitable washed steel slag aggregates are very strict, particularly that no detectable soft lime particles or lime oxide agglomerations shall be present

Special Provision No. 110S04 - Use of Recovered Concrete as Granular 'A', 'B' and 'M'

- use of recovered concrete (RCM) containing less than 20 percent asphalt coated material (RAP)

Special Provision No. 199F30 - Management of Excess Material

- requirements for management of excess rock, earth, swamp material, aggregate, asphalt concrete, concrete, natural wood and manufactured wood materials resulting from a contract

Special Provision No. 310S08 - Hot In-Place Recycled Mix (No. 313S30 very similar.)

- describes the sequence of operations for hot in-place recycling
 1. cleaning, heating and scarifying the existing asphalt pavement surface
 2. adding and mixing preheated fine aggregate and rejuvenating agent with the heated and scarified asphalt concrete, and redistributing the mix
 3. compacting the heated, scarified and rejuvenated asphalt mix
 4. sampling and testing
- gives requirements for heater scarifier machine (preheaters and heat reformer)

Special Provision No. 310S09 - Hot In-Place Recycled Mix with Integral Overlay

(No. 313S31 very similar.)

- same sequence of operations as Special Provision No. 310S08, with addition of placing a hot-mix overlay on the heated, scarified and rejuvenated asphalt mix immediately after it has been screeded, followed by compaction

Special Provision No. 314S01 - Mixing Recovered Bituminous Pavement with Granular to 40%

- describes uniformly blending reclaimed asphalt pavement (RAP) with granular material, so that the blended product contains no more than 40 percent RAP and is 100 percent passing the 26.5 mm sieve size with not more than 75 percent passing the 4.75 mm sieve size, and stockpiling in accordance with the requirements for coarse aggregates (if the granular material consists of crushed concrete (RCM) already containing RAP, this RAP must be included in the total amount of RAP permitted in the blended product)
- describes placing RAP (100 percent passing the 26.5 mm sieve size with not more than 75 percent passing the 4.75 mm sieve size) on the shoulder in place of granular material and uniformly processing the RAP with the underlying granular material by mechanical means so that no more than 40 percent RAP is incorporated with the granular material
- for trial contracts

Special Provision No. 314S02 - Mixing Recovered Bituminous Pavement with Granular to 30%

- similar to No. 314S01 with the blended product limited to no more than 30 percent reclaimed asphalt pavement (RAP)
- for regular use

Special Provision No. 399F14 - Recycled Hot Mix 25/75, 30/75, 35/65, 40/60, 45/55, 50/50, 60/40, 70/30

(No. 313F19 very similar.)

- gives the materials and construction requirements for recycled hot mix (RHM) of various specified recycling ratios (processed reclaimed asphalt pavement/new aggregates) from 25/75 (25 percent RAP/75 percent new aggregates to 70/30
- covers aspects such as RAP source and processing size, new coarse and fine aggregates (particularly new fine aggregate gradation as typically a fine, uniform sand required to meet mix design requirements) and new asphalt cement penetration (typically softer grade required for softening aged RAP asphalt cement)

Special Provision No. 399F34 - Recovered Bituminous Pavement on Shoulders

- similar to No. 314S01 with the specified processing depth with the underlying granular material such that the blended material contains no more than 40 percent reclaimed asphalt pavement (RAP) by volume
- for regular use

Special Provision No. 399F35 - In-Place Processing of Bituminous Pavement

- describes the processing of existing asphalt pavement and underlying granular material in place to a specified depth and then compacting this processed material as base course
- existing pavement processing and thorough mixing with underlying granular material carried out so that the blended material passes the 26.5 mm sieve size with not more than 75 percent passing the 4.75 mm sieve size
- specified processing depth such that the blended material contains no more than 50 percent reclaimed asphalt pavement (RAP) by volume

Special Provision, Cold In-Place Recycled Mix (New special provision in 1991.)

- describes the cold in-place reclaiming of existing asphalt pavement to a specified depth, sizing the reclaimed asphalt pavement (minus 37.5 mm size), mixing with binder (polymer-modified high float emulsified asphalt) and water (if required), spreading and compacting the recycled cold mix
- recycling train used consisting of a cold milling machine, screening and sizing unit and then mixing unit, followed by placing the recycled cold mix with a paver, compaction, curing and secondary compaction, if any

B 3.2 Cementitious Uses

Cementitious uses for granulated (and suitably pelletized) blast furnace slag, fly ash and silica fume are summarized in CAN/CSA-A23.1-M90 (Concrete Materials and Methods of Concrete Construction) and given in detail in CAN/CSA-A362-M89 (Blended Hydraulic Cement), CAN/CSA-A363-1988 (Cementitious Hydraulic Slag) and CAN/CSA-A23.5-M86 (Supplementary Cementing Materials).

Blended hydraulic cements must meet the requirements of CSA Standard A362 and are specified as:

Type	Name
10S	Portland Blast Furnace Slag
10SM	Slag-Modified Portland
10F	Portland Fly Ash
10FM	Fly Ash-Modified Portland
10SF	Portland Silica Fume

Supplementary cementing materials must meet the requirements of CSA Standard A23.5 (and CSA Standard A363 for Type H) and are specified as:

Type	Name
N	Natural pozzolan
F	Fly ash (Class F)
C	Fly ash (Class C)
G	Ground granulated blast furnace slag
H	Cementitious hydraulic slag
U	Silica fume

B 4. REFERENCES

B 4.1 Specifications and Uses

The current edition of these references should be consulted as specifications and manuals are always subject to revision.

- APAO, Construction Aggregate Consumer's Guide, Aggregate Producers' Association of Ontario, Mississauga, 1991.
- ASTM, Compilation of ASTM Standard Definitions, 7th Edition, American Society for Testing and Materials, Philadelphia, 1990.
- ASTM, "Construction", 1991 Annual Book of ASTM Standards, 1991: (See 1990 Construction Volumes for those not available until later in 1991.)
Volume 04.01/Cement; Lime; Gypsum (October 1991);
Volume 04.02/Concrete and Aggregates (July 1991);
Volume 04.03/Road and Paving Materials; Pavement Management Technologies (May 1991);
Volume 04.04/Roofing, Waterproofing, and Bituminous Materials (April 1991);
Volume 04.05/Chemical-Resistant Materials; Vitrified Clay, Concrete, Fiber-Cement Products; Mortars; Masonry (April 1991);
Volume 04.06/Thermal Insulation; Environmental Acoustics (October 1991);
Volume 04.07/Building Seals and Sealants; Fire Standards; Building Constructions (November 1991);
Volume 04.08/Soil and Rock; Dimension Stone; Geotextiles (March 1991); and
Volume 04.09/Wood (July 1991).
- ASTM, "Water and Environmental Technology", 1991 Annual Book of ASTM Standards, 1991:
Volume 11.04/Pesticides; Resource Recovery; Hazardous Substances and Oil Spill Responses; Waste Disposal; Biological Effects (August 1991).
- CSA, "Portland Cement/Masonry Cement/Blended Hydraulic Cement", CAN/CSA-A5/A8/A362-M89, Canadian Standards Association, Rexdale, 1989.
- CSA, "Concrete Materials and Methods of Concrete Construction/Methods of Test for Concrete", CAN/CSA-A23.1/A23.2-M90, 1990.
- CSA, "Supplementary Cementing Materials", CAN/CSA-A23.5-M86, 1986.
- CSA, "Cementitious Hydraulic Slag", CAN/CSA-A363-1988, 1988.
- Hanks, A.J. and Magni, E.R., "The Use of Recovered Bituminous and Concrete Materials in Granular and Earth", Report MI-137, Engineering Materials Office, Ontario Ministry of Transportation, Downsview, December 1989.
- Metro, "Specification for Hot Mix, Hot Laid Asphaltic Concrete", MT 701, Revision 1, Metric, Transportation Department, Municipality of Metropolitan Toronto Transportation Department, January 1991.
- MNR, "Geology, Properties and Economics", Limestone Industries of Ontario, Volume 1, Ontario Ministry of Natural Resources, Toronto, 1989.
- MTO, "Specifications and Special Provisions", Contract Design, Estimating and Documentation Manual, Volume 2, Chapter E, Ontario Ministry of Transportation, Downsview, current.
- MTO, Special Provision No. 199, Management of Excess Material, November 1988;
Special Provision No. 110S04, Use of Recovered Concrete As Granular 'A' and 'M' Aggregates, June 1989;
Special Provision No. 310S08, Hot In-Place Recycled Mix, December 1989;
Special Provision No. 310S09, Hot In-Place Recycled Mix with Integral Overlay, December 1989;
Special Provision No. 313F19, Recycled Hot Mix 25/75, 30/70, 35/65, 40/60, 45/55, 50/50, 60/40, 70/30, July 1990;
Special Provision No. 313S30, Hot In-Place Recycled Mix, July 1990;
Special Provision No. 313S31, Hot In-Place Recycled Mix with Integral Overlay, July 1990;

- Special Provision No. 314S01, Mixing Recovered Bituminous Pavement with Granular to 40%, October 1989;
 Special Provision No. 314S02, Mixing Recovered Bituminous Pavement with Granular to 30%, October 1989;
 Special Provision No. 399F14, Recycled Hot Mix 25/75, 30/70, 35/65, 40/60, 45/55, 50/50, 60/40, 70/30, March 1990;
 Special Provision No. 399F34, Recovered Bituminous Pavement on Shoulders, June 1989;
 Special Provision No. 399F35, In-Place Processing of Bituminous Pavement, June 1989; and
 Special Provision, Cold In-Place Recycled Mix, Contract No. 91-02.
- MTO, "Coarse Aggregates for HL1 and DFC", Designated Sources for Materials, DSM Number 3.05.25, current.
- MTO, Laboratory Testing Manual, current.
- OPSS, Ontario Provincial Standards, Ministry of Transportation, Municipal Engineers Association and Ministry of Environment, Ontario Provincial Standards Section, Ontario Ministry of Transportation, Downsview, current:
 OPSS 1001, Material Specification for Aggregates - General, May 1988;
 OPSS 1002, Material Specification for Aggregates - Concrete, May 1988;
 OPSS 1003, Material Specification for Aggregates - Asphaltic Concrete, Hot Mixed and Hot Laid, May 1988;
 OPSS 1004, Material Specification for Aggregates - Miscellaneous, January 1990;
 OPSS 1010, Material Specification for Aggregates - Granular A, B, M and Select Subgrade Material, May 1988;
 OPSS 1350, Material Specification for Concrete (Materials and Production), December 1983;
 OPSS 1149, Material Specification for Asphaltic Concrete, Hot Mix and Hot Laid Including Recycled and Speciality Mixes, June 1990 (intended only for MTO projects); and
 OPSS 1150, Material Specification for Asphaltic Concrete, Hot Mixed and Hot Laid, October 1989.
- Rogers, C.A., "Search for Skid Resistant Aggregates in Ontario", 19th Forum on the Geology of Industrial Minerals, Proceedings, Ontario Geological Survey Miscellaneous Paper 114, 1983.
- Rogers, C.A., "MTO Aggregate Specifications for Road Building and Related Construction", Aggregate Producers Association of Ontario Specifications Seminar, Ontario Ministry of Transportation, Downsview, January 1991.
- Senior, S.A. and Rogers, C.A., "New Test Methods for Predicting Coarse Aggregate Performance in Ontario", Transportation Association of Canada Annual Meeting, Ontario Ministry of Transportation, Downsview, September 1990.

B 4.2 General Design Manuals and Handbooks

- AI, "The Asphalt Handbook", Manual Series No. 4, 1989 Edition, Asphalt Institute, Lexington, 1989.
- CPCA, Design and Control of Concrete Mixtures, Canadian Metric Edition, Fourth Edition, Canadian Portland Cement Association, Ottawa, 1984.
- FHWA, Fly Ash Facts for Highway Engineers, Demonstration Projects Program, Federal Highway Administration, Washington, July 1986.
- MTO, Pavement Design and Rehabilitation Manual, Ontario Ministry of Transportation, Downsview, January 1990.
- NLA, "Lime Stabilization Construction Manual", Bulletin 326, Eighth Edition, National Lime Association, Arlington, 1985.
- NSA, "Processed Blast Furnace Slag, The All-Purpose Construction Aggregate", NSA 188-1, National Slag Association, Alexandria, 1988.

B 4.3 Obtaining Specifications, Design Manuals and Handbooks

Asphalt Institute (Extensive publications list on all aspects of asphalt technology)

Executive Offices and Research Center
Research Park Drive
P.O. Box 14052
Lexington, Kentucky 40512

Aggregate Producers' Association of Ontario (Publications on all aspects of Ontario aggregates industry)

365 Brunel Road, Unit 2
Mississauga, Ontario L4Z 1Z5

American Society for Testing and Materials (Extensive publications list on all aspects of construction materials)

1916 Race Street
Philadelphia, Pennsylvania 19103

Canadian Portland Cement Association (Extensive publications list on all aspects of concrete technology)

116 Albert Street
Ottawa, Ontario K1P 5G3

Canadian Standards Association (Extensive publications list on all aspects of construction materials)

178 Rexdale Boulevard
Rexdale, Ontario M9W 1R3

Federal Highway Administration (US Department of Transportation) (Extensive publications list on all aspects of transportation facilities materials and construction)

Demonstration Projects Division
400 7th Street SW
Washington, D.C. 20590

Municipality of Metropolitan Toronto Transportation Department

30th Floor, The Simpson Tower
401 Bay Street
Toronto, Ontario M5H 2Y4

Ministry of Transportation (Extensive publications list on all aspects of transportation facilities materials and construction)

Contract Design, Estimating and Documentation Manual
Laboratory Testing Manual
Ontario Provincial Standards (Complimentary copies are available to government, college, university and OPS Committee staff from Ontario Provincial Standards Section, 416-235-3530.)
Pavement Design and Rehabilitation Manual
Administration Services Office
Lower Level, East Building
1201 Wilson Avenue
Downsview, Ontario M3M 1J8

National Lime Association (Publications on all aspects of lime use)

3601 North Fairfax Drive
Arlington, Virginia 22201

National Slag Association (Publications on all aspects of blast furnace and steel slag use)

300 South Washington Street
Alexandria, Virginia 22314

Publications Ontario (Publications on all aspects of Ontario aggregates)

MGS Publications Services
5th Floor, 880 Bay Street
Toronto, Ontario M7A 1N8

Additional information sources are given in Appendix C.

APPENDIX C

KEY CONTACTS FOR ASSISTANCE

C 1. SIGNIFICANT INTEREST IN WASTES AND BYPRODUCTS USE AS AGGREGATES

Ontario Ministry of Natural Resources (MNR)

Aggregate and Petroleum Resources Section

880 Bay Street, Third Floor

Toronto, Ontario M5S 1Z8

(416) 314-2360

Manager: Ray Pichette

Senior Adviser, Economic and Business Analysis: Pervez Umar

Senior Policy Officer, Planning: Doug Vanderveer

Ontario Ministry of Transportation (MTO)

Highway Engineering Division

1201 Wilson Avenue

Downsview, Ontario M3M 1J8

Executive Director: Ed McCabe (416) 235-4402

Manager, Engineering Materials: Roger Northwood (416) 235-3732

Head, Soils and Aggregates Section: Chris Rogers (416) 235-3734

Senior Aggregates Resources Engineer: Zoltan Katona (416) 235-3738

Head, Bituminous Section: Dan Lynch (416) 235-3725

Head, Concrete Section: Hannah Schell (416) 235-3708

Ontario Ministry of the Environment (MOE)

2 St. Clair Avenue West, 14th Floor

Toronto, Ontario M4V 1L5

General Information (416) 323-4321

Waste Management Policy Section

Manager: George Rocoski (416) 323-5223

Waste Division Section

Manager: Neal Ahlberg (416) 323-5189

Municipal Waste Support Programs Section

Municipal Waste Reduction Unit

Supervisor: Joe Petoia (416) 323-5210

Ontario Hot Mix Producers Association (OHMPA)

365 Brunel Road, Unit 4

Mississauga, Ontario L4Z 1Z5

(416) 507-3707

Executive Secretary: Robert Bradford

Aggregate Producers' Association of Ontario (APAO)

365 Brunel Road, Unit 2

Mississauga, Ontario L4Z 1Z5

(416) 507-0711

Executive Director: Rob Cook

Canada Centre for Mineral and Energy Technology (CANMET)
Energy, Mines and Resources Canada
405 Rochester Street
Ottawa, Ontario K1A 0G1

Construction Materials Section
Head: Mohan Malhotra (613) 996-5449

Ontario Road Builders' Association (ORBA)
365 Brunel Road, Unit 1
Mississauga, Ontario L4Z 1Z5

(416) 507-1107
Executive Director: Arthur Ryan

Transportation Association of Canada (TAC)
2323 St. Laurent Boulevard
Ottawa, Ontario K1G 4K6

(613) 521-4052
Executive Director: Norman Brown

American Coal Ash Association (ACAA)
1000 16th Street NW
Washington, DC 20036
(202) 659-2303

Asphalt Recycling and Reclaiming Association (ARRA)
3 Church Circle, Suite 250
Annapolis, Maryland 21401
(301) 267-0023

Asphalt Rubber Producers Group (ARPG)
3336 N. 32nd Street, Suite 106
Phoenix, Arizona 85018
(602) 955-1141

National Slag Association (NSA)
300 South Washington Street
Alexandria, Virginia 22314
(703) 549-3111

The Scrap Tire Management Council
1400 K Street N.W., Suite 900
Washington, DC 20005
(202) 408-7781

C 2. GENERAL INTEREST IN WASTES AND BYPRODUCTS AS AGGREGATES

Canadian Testing Association (CTA)
Ontario Chapter
P.O. Box 240
Caledon, Ontario L0N 1C0
(519) 927-5852

Ontario Good Roads Association (OGRA)

5716 Coopers Avenue, Unit 7
Mississauga, Ontario L4Z 2E8
(416) 890-2248

Ready Mixed Concrete Association of Ontario (RMCAO)

365 Brunel Road, Unit 3
Mississauga, Ontario L4Z 1Z5
(416) 507-1122

C 3. GENERAL INTEREST IN WASTE MANAGEMENT (REDUCTION, REUSE AND RECYCLING)

Environment Canada

Ottawa, Ontario K1A 0H3
General Information: (819) 997-2800
Waste Management Division: (819) 997-3377

Metropolitan Toronto Works Department

Solid Waste Management Division
439 University Avenue
Toronto, Ontario M5G 1Y8
(416) 392-4200
Industrial Waste Reduction Hotline: (416) 392-4200

Ontario Waste Exchange (OWE)

Canadian Waste Materials Exchange (CWME)
ORTECH International
Sheridan Park Research Community
Mississauga, Ontario L5K 1B3
(416) 822-4111

Ontario Waste Management Association (OWMA)

4195 Dundas Street West, Suite 340
Etobicoke, Ontario M8X 1Y4
(416) 236-0172

Ontario Waste Management Corporation (OWMC)

2 Bloor Street West, 11th Floor
Toronto, Ontario M4W 3E2
(416) 923-2918

Region of Peel Waste Exchange Program

Regional Municipality of Peel
3190 Mavis Road
Mississauga, Ontario L5C 1T9
(416) 791-9400

C 4. GENERAL REFERENCES ON WASTE MANAGEMENT (REDUCTION, REUSE AND RECYCLING)

Profit from Pollution Prevention

Volume 1 (Second Edition, Revised), 1990
A Guide to Waste Reduction and Recycling in Canada
The Pollution Probe Foundation
12 Madison Avenue
Toronto, Ontario M5R 2S1
(416) 926-1043

(Comprehensive guide to waste reduction, reuse and recycling, including technical contacts.)

Pollution Engineering

Cahners Publishing Company

44 Cook Street

Denver, Colorado 80206

(Monthly covering water, wastes and air, with frequent overview articles on waste management topics.)

Scrap Processing and Recycling

Institute of Scrap Recycling Industries, Inc. (ISRI)

1627 K Street N.W.

Washington, D.C. 20006

(Bimonthly on waste recycling.)

APPENDIX D

METRIC CONVERSIONS AND ABBREVIATIONS

D 1. METRIC CONVERSIONS

1 kilometre (km)	=	0.6214 miles (statute)
1 metre (m)	=	3.2808 feet
1 millimetre (mm)	=	0.0397 inches
1 hectare (ha)	=	2.4711 acres
1 square metre (m ²)	=	10.7639 square feet
1 cubic metre (m ³)	=	1.3080 cubic yards
1 litre (l)	=	0.2200 gallons (imperial)
1 kilogram (kg)	=	2.2046 pounds
1 metric tonne (t)	=	1.1023 short tons
	=	2204.6 pounds

D 2. ABBREVIATIONS

AC	asphalt cement
AI	Asphalt Institute
APAO	Aggregate Producers' Association of Ontario
ASTM	American Society for Testing and Materials
CPCA	Canadian Portland Cement Association
CSA	Canadian Standards Association
GTA	Greater Toronto Area
HMA	hot-mix asphalt (hot-mix asphalt concrete)
Metro	Municipality of Metropolitan Toronto
MNR	Ontario Ministry of Natural Resources
MOE	Ontario Ministry of the Environment
MT	Transportation Department, Municipality of Metropolitan Toronto
MTO	Ontario Ministry of Transportation (formerly MTC)
OHMPA	Ontario Hot Mix Producers Association
OPSS	Ontario Provincial Standard Specification
ORBA	Ontario Road Builders Association
PC	portland cement
PCC	portland cement concrete
RAM	reclaimed aggregate material
RAP	reclaimed asphalt pavement
RCM	reclaimed concrete material
RHM	recycled hot mix
SP	special provision
TAC	Transportation Association of Canada
3Rs	reduce, reuse and recycle